Titre: Title:	Réseau social pour l'initiation de synergies industrielles
Auteur: Author:	Mohamed Raouf Ghali
Date:	2017
Type:	Mémoire ou thèse / Dissertation or Thesis
Référence: Citation:	Ghali, M. R. (2017). Réseau social pour l'initiation de synergies industrielles [Thèse de doctorat, École Polytechnique de Montréal]. PolyPublie. https://publications.polymtl.ca/2766/

URL de PolyPublie: PolyPublie URL:	https://publications.polymtl.ca/2766/
Directeurs de recherche: Advisors:	Jean-Marc Frayret
Programme: Program:	Génie industriel

UNIVERSITÉ DE MONTRÉAL

RÉSEAU SOCIAL POUR L'INITIATION DE SYNERGIES INDUSTRIELLES

MOHAMED RAOUF GHALI

DÉPARTEMENT DE MATHÉMATIQUES ET DE GÉNIE INDUSTRIEL

ÉCOLE POLYTECHNIQUE DE MONTRÉAL

THÈSE PRÉSENTÉE EN VUE DE L'OBTENTION

DU DIPLÔME DE PHILOSOPHIAE DOCTOR

(GÉNIE INDUSTRIEL)

MAI 2017

UNIVERSITÉ DE MONTRÉAL

ÉCOLE POLYTECHNIQUE DE MONTRÉAL

Cette thèse intitulée :

RÉSEAU SOCIAL POUR L'INITIATION DE SYNERGIES INDUSTRIELLES

présentée par : GHALI Mohamed Raouf

en vue de l'obtention du diplôme de : Philosophiae Doctor

a été dûment acceptée par le jury d'examen constitué de :

M. PELLERIN Robert, Ph. D., président

M. FRAYRET Jean-Marc, Ph. D, membre et directeur de recherche

M. MARGNI Manuele, Doctorat, membre

M. CHAABANE Amin, Ph. D, membre externe

DÉDICACE

À ma femme Hajer pour sa présence et son

soutien permanent

REMERCIEMENTS

Venir au Canada en 2007 avec un objectif et projet de vie (le doctorat) n'aurait pas été possible sans la contribution effective de mon directeur de recherche et de ma famille. D'abord, je tiens à remercier M. Frayret, mon directeur de thèse, pour avoir accepté de me guider au cours de ces cinq dernières années, et de m'avoir fait découvrir l'écologie industrielle et des sujets d'étude passionnants. Je n'ose imaginer à quoi ressemblerait ce manuscrit sans ses conseils avisés, son jugement clairvoyant et sa disponibilité constante. Jean-Marc, je te remercie également pour ta patience, ta flexibilité et ton professionnalisme. Je ne peux que témoigner de la chance que j'ai eue d'avoir un directeur comme toi. Je remercie également M. Robert pour sa contribution effective dans mon premier papier malgré ses engagements sur le plan personnel.

Ce projet de recherche a vu le jour dans le cadre d'un partenariat université-entreprise. Ce partenariat avec le Centre de Transfert technologique en Écologie Industrielle (CTTÉI) s'étendait sur trois ans. J'ai pu côtoyer des personnes dévouées et attentionnées ayant pour unique souci le développement durable. Je pense par exemple à Karine Markewich, Jennifer Pinna et Claude Maheux-Picard. Être accueilli au sein du CTTÉI fut pour moi une chance inouïe.

Finalement, je remercie de tout cœur les membres de ma famille : ma mère, ma femme et mon père pour leur présence amicale, leurs encouragements et leur soutien sans faille. Je remercie énormément ma femme pour sa patience et son soutien durant ces deux dernières années de la thèse. Cela n'a pas été du tout évident. Je vous adresse, par ces quelques mots, ma plus profonde reconnaissance et gratitude pour vos encouragements, votre patience, votre soutien et tout ce que vous avez fait pour moi depuis que je suis sur les bancs d'école. Je remercie la belle Rania, mon bébé d'amour qui illumine ma vie.

RÉSUMÉ

La recherche présentée dans cette thèse puise dans le domaine de l'écologie industrielle, précisément la symbiose industrielle (SI), en supposant qu'il est possible pour une ou plusieurs entreprises de trouver des débouchés à leurs matières résiduelles. La symbiose qui commence généralement par des relations d'affaires, des opérations de rapprochement et de collaboration entre deux ou plusieurs entreprises (synergies industrielles) aboutit à la mise en œuvre du développement durable à une échelle territoriale.

Jusqu'à récemment, la majorité des contributions dans ce domaine portait sur les aspects conceptuels de la symbiose industrielle et les études de cas. Les études de cas avaient pour but de présenter un aperçu général des initiatives ou de projets spécifiques de symbiose industrielle ou d'examiner plusieurs cas au niveau d'une industrie en particulier, d'une région, d'une ville ou même d'une entreprise afin d'effectuer principalement des comparaisons. Plus tard, d'autres études ont commencé à analyser la performance économique et environnementale de la symbiose industrielle et ont ainsi proposé de nouvelles idées ou stratégies pour sa mise en œuvre. Malheureusement, les aspects sociaux sont restés la plupart du temps peu explorés. Bien que les dernières publications aient partiellement abordé ces lacunes, Spekkink, (2016), entre autres, reconnaît le rôle joué par les aspects sociaux, et plus particulièrement l'aspect de la confiance, et bien que la modélisation ait relativement aidé à comprendre l'évolution de la symbiose industrielle et à optimiser les flux de matières en expérimentant des scénarios divers (Cao *et al.*, 2009; Kim *et al.*, 2012), il y a encore peu de compréhension en ce qui concerne l'apport des dimensions sociales et comment elles affectent l'émergence et le fonctionnement des réseaux de symbioses industrielles.

L'objectif de ce travail est dans un premier temps de présenter d'une part, la valeur ajoutée des médias sociaux ainsi que leurs fonctions dans l'initiation, la promotion et le développement d'un réseau industriel visant l'identification d'opportunités efficaces de mise en valeur de sous-produits en contexte de symbiose industrielle. Ce travail propose notamment un cadre conceptuel permettant de mieux comprendre la contribution des médias sociaux au développement des symbioses industrielles. Ce travail propose de plus une application du web sémantique au partage des connaissances et à l'identification d'opportunités de synergies industrielles dans le cadre des réseaux sociaux. Finalement, un modèle de simulation à base d'agents est proposé pour illustrer

l'influence des relations sociales dans la création des synergies et des symbioses dans un parc industriel selon différentes structures de réseaux (random vs scale-free).

À travers ce travail, les conclusions suivantes ont pu être tirées.

La première conclusion démontre qu’un réseau social vert enrichi de fonctions sociales peut contribuer à l’émergence de synergies industrielles à travers l’apprentissage, le partage d’informations, le tissage de relations et grâce au rôle de coordination communautaire qu'il peut jouer. Ceci dans le but de soutenir le développement de la symbiose industrielle et de réduire ainsi l’impact collectif des communautés industrielles.

La deuxième conclusion démontre qu’il est possible de produire de nouvelles inférences à partir de données issues du web sémantique fondées sur des tags préalablement déterminés et que l’ontologie proposée a la robustesse nécessaire pour réaliser cette tâche. En effet, la structure de l’ontologie exprimée en OWL (Langage interopérable du web sémantique permettant de concevoir des fichiers répondants au vocabulaire et à la sémantique de la logique des descriptions) et son exploitation par les requêtes SPARQL (le langage de requête du web sémantique) a permis de générer des relations validées entre des ressources issues du web afin d’identifier des relations de synergies potentielles entre acteurs industriels. Notons tout de même qu’un certain travail reste à réaliser avant d’envisager de mettre en production une telle ontologie. En effet, il importe d’identifier clairement les sources web d’informations et d'analyser leur qualité d'un point de vue du contenu des connaissances. Pour chacune de ces sources, il importe de méticuleusement choisir les tags appropriés et de les regrouper sous des catégories exploitables. De plus, une analyse plus approfondie des cas d’utilisation de cette approche permettrait aussi de mieux structurer les ontologies et d’orienter leur développement pour la mise en œuvre d’une solution répondant adéquatement aux exigences attendues du système.

Finalement, la troisième contribution de ce travail supporte la conclusion que la dynamique et la structure sociale impliquées au sein des parcs industriels influencent le développement des symbioses industrielles. Bien que le modèle de simulation utilisé et les expériences réalisées ne permettent que de déterminer de façon générale leur impact sur la vitesse de développement des synergies industrielles, ces expériences démontrent que dans des conditions générales similaires, la structure et la dynamique des relations sociales influencent la matérialisation des synergies potentielles existantes au sein d’un groupe d’acteurs industriels. Cependant, plus de travail est nécessaire pour valider ces résultats et étudier plus en profondeur à la fois les facteurs sociaux qui favorisent la création des synergies industrielles, mais aussi pour étudier l'impact potentiel de médias sociaux dans divers contextes et dynamiques de symbioses industrielles. De plus, sur le plan méthodologique, les expériences réalisées illustrent comment un tel modèle peut être utilisé comme outil complémentaire aux études de cas empiriques très répandues dans ce domaine.

Ces trois contributions ont pour buts à long terme de permettre le développement d'outils informatiques afin de supporter les animateurs de réseaux éco-industriels, les agents de développement économique, les conseils municipaux, les consultants ou les centres de recherche dans l'évaluation des bénéfices économiques et environnementaux potentiels de synergies industrielles.

Ce projet a été mené en collaboration avec le *Centre de Transfert Technologique en Écologie Industrielle*, situé à Sorel- Tracy, Québec, Canada.

ABSTRACT

The research presented in this thesis draws from the field of industrial ecology, precisely industrial symbiosis (IS), assuming that it is possible for a company or more to find outlets for their waste. The symbiosis that usually starts with business relations, reconciliation of transactions and collaboration between two or more industrial synergies results in the implementation of sustainable development implementation at a territorial level.

Until recently, the majority of contributions in this area focused on the conceptual aspects of industrial symbiosis and case studies. The purpose of the case studies was to provide a general overview of a specific industrial symbiosis project or to examine several cases at the level of a particular industry, region, city or even a company to perform mainly comparisons. Later, other studies began to analyze the economic and environmental performance of industrial symbiosis and thus proposed new ideas or strategies for its implementation. Unfortunately, the social aspects have remained little explored. Although recent publications have partially addressed these gaps, Spekkink (2016), among others, acknowledges the role played by social aspects, particularly the aspect of trust. Although modeling has helped to understand the evolution of industrial symbiosis and the optimization of material flows by experimenting with various scenarios (Cao et al., 2009, Kim et al., 2012), there is still little understanding of the contribution of dimensions and how they affect the emergence and functioning of industrial symbiosis networks.

On one hand, the objective of this work is to present the added value of social media and their functions in the initiation, promotion and development of an industrial network that is aimed at identifying opportunities as efficient by-product development in the context of industrial symbiosis. This work proposes in particular a conceptual framework to better understand the contribution of social media to the development of industrial symbiosis. On the other hand, this work also proposes an application of the semantic web to the sharing of knowledge and the identification of opportunities for industrial synergies within the framework of the social networks. Finally, an agent-based simulation model is proposed to illustrate the influence of social relations in the creation of synergies and symbiosis in an industrial park according to different network structures (random vs scale-free).

Through this work, the following conclusions can be drawn.

The first conclusion demonstrates that a green social network enriched with social functions can contribute to the emergence of industrial synergies through learning, information sharing, relationship building and community coordination. This emergence supports the development of industrial symbiosis and thus reduces the collective impact of industrial communities.

The second conclusion demonstrates that it is possible to produce new inferences from semantic web data based on predetermined tags and that the proposed ontology has the necessary robustness to perform this task. Indeed, the structure of the ontology expressed in OWL (Semantic web interoperable language allowed to design files that respond to the vocabulary and semantics of descriptive logic) and its use by SPARQL queries (the query language of the web Semantics) enabled the generation of validated relationships between resources from the web in order to identify potential synergies between industrial players. Let us note, however, that some work remains to be realized before considering putting such an ontology into production. Indeed, it is crucial to clearly identify web sources of information and to analyze their quality from a knowledge content perspective. For each of these sources, it is important to carefully select the appropriate tags and group them into exploitable categories. Moreover, a more in-depth analysis of the use of this approach would also make it possible to better structure the ontologies and guide their development in order to implement a solution that meets the expected requirements of the system.

Finally, the third contribution of this work supports the conclusion that the dynamics and social structure involved in industrial parks' influence the development of industrial symbiosis. Although the simulation model used and the experiments carried out only allow us to determine in general their impact on the rate of development of industrial synergies, these experiments show that under similar general conditions the structure and dynamics of social relations influence the potential synergies within a group of industrial players. However, more work is needed to validate these findings and to explore more deeply both the social factors that favor the creation of industrial synergies and also to study the potential impact of social media in various contexts and dynamics of industrial symbiosis. Moreover, from the methodological point of view, the experiments carried out illustrate how such a model can be used as a complementary tool to the empirical case studies that are widely used in this field.

The three long-term objectives of these three contributions are to enable the development of IT tools to support eco-industrial network leaders, economic development officers, municipal councils, consultants or research centers in the evaluation of economic and environmental benefits of industrial synergies.

This project was conducted in collaboration with the Technology Transfer Centre in Industrial Ecology, located in Sorel-Tracy, Quebec, Canada.

TABLE DES MATIÈRES

LISTE DES TABLEAUX

LISTE DES FIGURES

LISTE DES SIGLES ET ABRÉVIATIONS

ABM	Agent Based Modeling
B2B	Business To Business
CF	Cash Flow
CTTEI	Centre de Transfert Technologique en Écologie Industrielle
EIP	Eco-Industrial Park
FAST	Facility Synergy Tool
FQRNT	Fonds Québécois de Recherche en Nature et en Technologies
GIS	Geographic Information System
GSN	Green Social Networking
ICT	Information and Communication Technology
IS	Industrial Symbiosis
ISIS	Facility Synergy Tool
ISDATA	Industrial Symbiosis Data Sources
ISN	Industrial Symbiosis Network
LOD	Linked Open Data
NISP	National Industrial Symbiosis Program
NPV	Net Present Value
NSERC	Natural Sciences and Engineering Research Council of Canada
RAV	Reason-Able Views
SM	Social Media
SN	Social Networks
TEDA	Tianjim Economic-Technological Development Area

CHAPITRE 1 INTRODUCTION

1.1 Mise en contexte

Grâce au recyclage de flux de matière et d'énergie, l'écologie industrielle permet non seulement de réduire la pollution, mais vise surtout à améliorer l'efficacité des ressources et de l'énergie du système industriel. De telles améliorations sont possibles par l’identification et la mise en œuvre de synergies entre des entreprises situées sur un territoire donné, menant à un concept baptisé symbiose industrielle qui a pour objectif de boucler les flux de matières et d’énergie à plus ou moins grande échelle en encourageant la création de réseaux entre les entreprises d’échanges d'énergie et de matières.

Ce concept fournit une perspective systémique utile pour soutenir le développement durable tout en assurant la création de valeur pour les parties prenantes. La mise en œuvre de la durabilité du développement est à considérer dans le cadre de la mondialisation des économies où la ressource critique est le savoir-faire et l’intelligence de l’information. Cela nécessite de modifier les stratégies de développement et les modes d’organisation de l’entreprise. Cette mise en œuvre concerne directement les modes de gouvernance et les domaines de gestion, du management, de la communication, des technologies de fabrication, de la logistique et du design des produits (écoconception).

Une symbiose industrielle est un réseau d’entreprises utilisatrices et productrices de résidus maillées entre elles par des échanges de sous-produits et résidus de matières ou d’énergie. Dans ce contexte, les prestataires de service tels que National Industrial Symbiosis Program (NISP) en Grande-Bretagne, ou le Centre de Transfert Technologique en Écologie Industrielle (CTTÉI) au Québec, Canada, ont pour mission de favoriser la coopération au sein du réseau, et ainsi d’améliorer la performance environnementale des entreprises. Même si ces prestataires de service disposent de bases de données avec des fonctions de filtrage simple afin d’identifier des opportunités d’échange, l’identification de ces opportunités de synergie est principalement basée sur la compatibilité entre des catégories de résidus et des besoins de matières des entreprises, et les entreprises impliquées dépendent fortement de tierces parties ou de leurs propres réseaux de contacts personnels pour identifier ces opportunités.

Pour situer notre thème de recherche, nous nous sommes posé les questions suivantes, qui ont profondément influencé et mis en contexte notre problématique ainsi que le choix de notre objet de recherche : Quel est le rôle des médias sociaux dans l'initiation de synergie industrielle et quelles sont les variables et paramètres qui influencent une telle initiation ? Comment la simulation à base d'agent contribue à notre compréhension de la symbiose industrielle ?

Compte tenu de la question générale de recherche, il nous est apparu essentiel d'en préciser la teneur pour mieux circonscrire nos buts, nos objectifs et évidemment la méthodologie que nous avons choisie. Nous avons ainsi retenu la question spécifique suivante :

« Comment (a) initier la découverte et mise en œuvre des opportunités de synergies industrielles, et plus particulièrement (b) coordonner les actions et les interactions des acteurs des systèmes industriels pour supporter le partage des informations ? »

En fonction des interrogations susmentionnées, nous nous sommes fixés les objectifs spécifiques suivants :

- Proposer un cadre conceptuel décrivant le rôle potentiel des réseaux sociaux pour initier et mettre en œuvre les opportunités de synergies industrielles.
- Proposer un outil permettant de faciliter l'échange d'informations entre partenaires potentiels et la découverte d'opportunités de synergies industrielles.
- Proposer un cadre et un outil permettant d'évaluer l'impact de la dynamique et de la structure des échanges d'informations au sein d'un réseau social d'un groupe d'entreprises sur l'initiation de synergies industrielles.

Pour atteindre ces objectifs, ce projet propose plusieurs phases de recherche.

– Concernant le premier objectif, l'approche méthodologique a consisté d'une part à analyser les nombreuses études de cas trouvées dans la littérature, et d'autre part à justifier le rôle des médias sociaux. A cette fin, nous avons réalisé une analyse systématique des fonctions des médias sociaux professionnels ou non-professionnels et ceci, dans le but de créer un cadre portant sur les fonctionnalités de partage de l'information et la mise en relation supportant l'initialisation et l'opération d'échanges de résidus industriels. Ensuite, une approche conceptuelle baptisée *Réseau Social Vert* (Green Social Networking) a été proposée (Chapitre 4).

- En ce qui concerne le deuxième objectif, la méthodologie retenue consiste de démonter qu'il est possible, à partir du données ouvertes (*Linked Open Data (LOD)* d'associer des entreprises et des ressources qui sont répertoriées dans l'ontologie de Dbpedia (www.dbpedia.org) selon un ensemble de critères définis dans une ontologie locale qui est appelée **OntoEco**. Le but sera atteint par la modélisation de l'OntEco dans le formalisme du Web Ontology Language(OWL) et par la conception et l'implantation des requêtes SPARQL permettant la réalisation des cas d'utilisation (Chapitre 5). Un cas d'utilisation (CU) se définit comme la description des processus, des usages et des artefacts logiciels nécessaires à l'accomplissement d'une tâche. Dans le cadre de ce projet, le CU associe un usage déterminé à atteindre avec l'élément ontologique permettant d'accomplir l'usage à chaque élément ontologique.

Le deuxième objectif est une extension du premier, car un réseau social vert contribue à stimuler les liens sociaux et conduit à l'identification des compatibilités de flux matériels, mais ne fournit pas les moyens d'organiser, de connecter et de récupérer des données, des informations et des connaissances pour permettre efficacement l'extraction d'informations pertinentes et de connaissances sur les échanges de matières résiduelles. Ceci est le rôle du web sémantique où l'ontologie, le noyau web sémantique, joue un rôle de structuration de la connaissance et de l'information, tandis que les réseaux sociaux jouent un rôle d'avant-garde permettant des interactions directes entre utilisateurs et le partage de leurs expériences individuelles pour susciter des synergies industrielles possibles.

Finalement, afin d'atteindre notre troisième objectif, nous avons utilisé la modélisation à base d'agents afin d'illustrer l'influence des aspects sociaux dans le développement des symbioses industrielles, et notamment la contribution de la structure et de la dynamique sociales. (Chapitre 6). Un dispositif expérimental informatique appelé simulateur (Netlogo) a été utilisé à la fois pour implémenter un modèle à base d'agents de la dynamique des échanges sociaux au sein d'un parc industriel, et pour simuler différents contextes sociaux-techniques.

Notons de plus que dans le cadre de ce projet, une plateforme technologique baptisée ecobiose.com a été développée en collaboration avec le CTTÉI. Ce réseau social prototype a pour fonction l'échange d'informations, la diffusion de la connaissance en écologie industrielle, et l'aide à la création des réseaux de synergies industrielles via des fonctions d'identification automatiques. Ce travail de conception et de développement informatique n'est pas directement présenté dans le cadre de cette thèse, mais un aperçu a été présenté en annexe à titre indicatif (C.f annexe).

1.2 Structure de la thèse

Cette thèse présente dans un premier chapitre les objectifs de recherche ainsi que la méthodologie adoptée. Le second chapitre propose une revue de littérature structurée autour de la symbiose industrielle, sa dimension sociale et son développement. Par la suite, on y expose la simulation à base d'agent, le Web sémantique et le Web sémantique social (chapitre 2). Les chapitres 3, 4, 5 exposent l'essentiel des résultats de la recherche sous forme de trois publications scientifiques suivantes couvrant l'ensemble des objectifs de recherche:

Ghali, M.R., Frayret, J.-M., Robert, J.-M., 2016. Green social networking: Concept and Potential Applications to Initiate Industrial Synergies. *Journal of Cleaner Production*. 115(1), pp. 23–35.

Ghali, M.R., Frayret, J.-M., 2016. Social Semantic Web Framework for Industrial Synergies Initiation. Submitted to *Computers & Chemical Engineering*.

Ghali, M.R., Frayret, J.-M., Ahabchane, C., 2017. Agent-Based Simulation of Industrial Symbiosis Evolution: Impact of Social Networks. Submitted to *Journal of Cleaner Production*.

Enfin, le chapitre 6 offre une synthèse des travaux ainsi qu'une discussion générale pour finalement mener à la conclusion et aux recommandations au chapitre 7.

CHAPITRE 2 REVUE DE LA LITTÉRATURE

Afin d'encadrer notre recherche et d'atteindre les objectifs susmentionnés, notre revue de la littérature se concentre d'abord sur le concept de la symbiose industrielle et ses dimensions sociales, puis elle se penche sur l'apport du Web sémantique social à la symbiose industrielle comme étant un modèle web pour la création, la gestion et le partage d'informations grâce à l'utilisation combinée des approches du web social (web 2.0) et du web sémantique. Enfin, la revue présente la modélisation et la simulation à base d'agents et leurs apports à l'étude de la dynamique des réseaux symbiotiques.

2.1 Le développement des symbioses industrielles

L'écologie industrielle est une discipline qui s'intéresse à la préservation des ressources naturelles. Elle est mise en application à travers la mise en œuvre de symbioses industrielles, ou parcs industriels où les déchets et sous-produit d'une entreprise deviennent une ressource pour une autre entreprise. Le concept de symbiose industrielle est généralement perçu dans la littérature comme étant un ensemble de synergies industrielles, soit un ensemble d'entreprises au sein duquel il y a des échanges de sous-produits et du partage de services entre entreprises (Van Berkel, Majer, & Stehlik, 2007; Chertow, Ashton, & Espinosa, 2008). La dimension réseau et la collaboration sont deux éléments clés. En d'autres termes, la synergie est un échange entre deux parfois trois entreprises alors que la symbiose est un réseau découlant de ses échanges. La communauté des affaires internationales (International Business Community) utilise l'expression synergie des sous-produits pour décrire les échanges dans un réseau symbiotique (Chertow, 2016). En effet, la littérature a peu abordé le concept de la synergie industrielle, son développement et les moyens de le développer. La majorité des publications parues jusqu'à maintenant portaient sur le réseau des échanges (la symbiose industrielle). Dans ce papier nous avons fait le choix de présenter la littérature sur la symbiose industrielle.

L'intérêt et la compréhension de la symbiose industrielle se sont développés au fil des années (Lowe and Evans, 1995; Chertow, 2000; Hardy and Graedel, 2002; Korhonen, 2005 ; Ashton, 2009; Gregson et al., 2012; Yu et al., 2014 ; Zhang et al., 2014; Chertow, 2016). Le succès de la symbiose industrielle de Kalundborg (Dougherty, 1997; Jacobsen, 2006) a joué un rôle prépondérant dans la recherche et un cas de référence pour d'autres chercheurs (Van Leeuwen, Vermeulen, & Glasbergen, 2003; Roberts, 2004), qui ont cherché à la reproduire en faisant la démonstration des avantages économiques et environnementaux.

Les chercheurs ont depuis mis l'accent sur l'étude de cas afin d'avoir une meilleure compréhension de la symbiose industrielle et sa façon de développer (Zhu et al., 2007; Park et al., 2008; Baas, 2008; Elabras et al., 2009; Van Berkel et al., 2009; Shi et al., 2010; Sakr et al., 2011; Taddeo et al., 2012; Dong et al., 2013).

Certes, le fait de collecter des données, de faire des observations et des entrevues en utilisant des sources de données existantes afin d'élaborer un cadre d'analyse est nécessaire au développement de la compréhension de symbioses industrielles. Cependant, ces études de cas ne contribuent pas directement à l'élaboration d'outils pour stimuler le potentiel d'identification de synergies. En effet, les ressources qui doivent être échangées entre deux ou plusieurs entreprises ne sont pas toujours des produits standardisés. Elles nécessitent une analyse supplémentaire, une transformation ou un traitement potentiel. Plus important encore, l'investissement dans l'équipement nécessaire ou dans d'autres actifs physiques pour aider à l'exécution d'un tel échange nécessite une évaluation économique des parties prenantes.

En conséquence, la réaction initiale des chercheurs consistait à traiter le réseau de synergies industrielles (la symbiose industrielle) comme étant un système complexe auto-organisée (Dijkema & Basson, 2009; Boons, Spekkink, & Mouzakitis, 2011, Chertow & Ehrenfeld, 2012). L'auto-organisation est une propriété d'un système complexe qui peut étendre ou modifier une structure interne d'une manière spontanée et adaptative. Avec l'auto-organisation, la structure de réseau émerge en elle-même, sans être dirigée ou formée par une source extérieure. En théorie de la gestion, l'existence de communautés auto-organisées, comprenant des entreprises qui partagent des intérêts, des protocoles et des infrastructures est bien documentée (Miles, Snow, Fjeldstad, Miles, & Lettl, 2010).

Bien qu'il y ait plusieurs études sur le succès de la symbiose industrielle auto-organisée (Gibbs, Deutz, & Procter, 2005; Chertow, 2007), d'autres études ont identifié des formes mixtes d'évolution vers la symbiose industrielle dans les communautés d'entreprises en faisant valoir que le processus de la symbiose industrielle ne se produit pas spontanément (Boons & Baas, 1997). De telles études soulignent que les symbioses industrielles peuvent être efficacement conçues et promues par des initiatives nationales ou des instruments politiques impliquant des approches territoriales (Park, Rene, Choi, & Chiu, 2008; Zhang et al., 2010; Shi et al., 2010). Ce processus planifié (top down) de mise en réseau se produit lorsque « *les parties interagissent pour atteindre, planifier, coordonner, ou décider de leurs activités individuelles et collectives* » (traduit de Paquin & Howard-Grenville, 2012). L'un des exemples les plus réussis du modèle planifié est le NISP au Royaume-Uni, qui est une initiative du secteur privé du Conseil d'affaires pour le développement durable. Ce modèle considère l'ensemble du pays comme un parc éco-industriel (Jensen, Basson, Hellawell, Bailey, & Leach, 2011) facilitant la connexion des membres et la diffusion des connaissances entre eux (Lowe, 1997; Ashton, 2008; Costa & Ferraro, 2010).

La proximité géographique des organisations est un facteur important dans le développement logistique de synergies puisqu'elle favorise techniquement les échanges de matières et d'énergie entre entreprises (Lyon, 2007; Jensen, Basson, Hellawell, Bailey, & Leach, 2011). D'ailleurs, l'échelle spatiale a été bien étudiée et exposée par plusieurs auteurs (Lambert & Boons, 2002 ; Sterr & Ott, 2004). Or, contrairement à ceux-ci, Lombardi & Laybourn (2012) ont noté que l'application de la symbiose industrielle ne se limite plus à la proximité géographique puisque l'accent doit être mise davantage sur l'éco-innovation et le partage de la connaissance. Le partage de la connaissance dans la symbiose industrielle comme la collaboration (Chertow, 2000) implique que les parties prenantes (parties impliquées dans la synergie ou la symbiose) travaillent ensemble sur des objectifs communs. Cela signifie qu'à côté des relations physiques (échanges de matière ou d'énergie), il y a aussi des relations sociales et une dynamique des réseaux inter-organisationnels (Domenech & Davies, 2011, Paquin & Howard-Grenville, 2012, Ashton & Bain, 2012).

C'est ainsi qu'il y a eu un intérêt pour l'étude de l'influence des dimensions sociales, pas en termes de création d'emplois, mais au niveau des relations sociales entre les parties impliquées dans la symbiose. Celles-ci comprennent la confiance, la hiérarchie et la coercition (Ashton, 2008; Velenturf & Jensen, 2015) ; l'apprentissage collectif (Chertow, Ashton, & Espinosa, 2008); l'*embeddedness* (Domenech & Davies, 2011; Ashton & Bain, 2012) ; ainsi que la collaboration (Lombardi & Laybourn, 2012). Nous notons que la majorité de la littérature concernant l'influence des dimensions sociales sur les réseaux symbiotiques met l'accent sur la confiance. La section suivante présentera les aspects sociaux associés à la symbiose industrielle tels qu'ils ont été décrits dans la littérature.

2.2 Les aspects sociaux de la symbiose industrielle

Les réseaux de symbiose industrielle sont des réseaux sociaux (Povh, 2015). Cela implique que les nœuds de tels réseaux (entreprises, acteurs politiques, intermédiaires de services) sont des acteurs sociaux opérant dans le cadre de la rationalité limitée. L'échange de ressources se déroulant entre ses acteurs sociaux implique un certain niveau de connaissance, la volonté de s'impliquer et un certain niveau de confiance.

La confiance joue un rôle important dans l'établissement de relations entre les parties (Gibbs, 2003; Gibbs, Deutz, & Procter, 2005; Ashton, 2008; Chertow & Ehrenfeld, 2012; Ashton & Bain, 2012; Taddeo, Simboli, & Morgante, 2012) puisque la possibilité de comportement opportuniste des partenaires ne peut pas être toujours éliminée par des contrats formels. L'établissement de la confiance est primordial pour la construction d'un réseau entre les différentes entreprises industrielles, qui peuvent à leur tour créer des niveaux élevés d'efficacité au cours de la phase opérationnelle d'une synergie industrielle (Baas, De Dreu, & Nijstad, 2008).

La confiance dépend des actions passées et présentes, et des interactions au sein d'un groupe d'acteurs, sur la base desquelles ces derniers choisissent les actions à poser en fonction des attentes concernant les futures actions de coopération des autres acteurs. La confiance pour Granovetter est une caractéristique des relations sociales et des réseaux sociaux, et une des conséquences d'un concept d'*embeddedness* (Granovetter, 1985).

Baas (2008) a introduit le concept d'*embeddedness* (Uzzi, 1997; Granovetter, 1985), selon lequel les activités économiques sont intégrées dans des structures de relations sociales, qui peuvent différer dans le temps et dans l'espace, en stipulant que les activités de symbiose industrielle sont façonnées par le contexte cognitif, structurel, culturel, politique, spatiale et temporel où elles se déroulent. Plus tard, Domenech & Davies (2011) and Ashton & Bain (2012) ont étudié le lien entre *l'embeddedness* et le développement de la symbiose industrielle. Ils remarquent ainsi que les éléments sociaux jouent un rôle prépondérant dans le développement des réseaux symbiotiques comme l'ont avancé Domenech & Davies (2009). Ils s'entendent pour dire que :

> *« Au delà de la faisabilité technique des échanges, les éléments sociaux jouent également un rôle crucial dans le développement des réseaux de symbiose industrielle »* (Domenech & Davies, 2009)

Actuellement, ces éléments sociaux sont favorisés par des prestataires de services tels que des organismes gouvernementaux (Burström & Korhonen, 2001), des courtiers (Paquin & Howard-Grenville, 2012) ou des associations professionnelles (Heeres, Vermeulen, & de Walle, 2004) ayant pour but l'identification de synergies potentielles et l'octroi de conseils sur les actions nécessaires pour faciliter la collaboration entre partenaires et assurer la durabilité de l'environnement (Mirata, 2004). Cependant, ces prestataires de services ne créent et ne diffusent pas auprès des deux parties de synergie industrielle l'information sur le potentiel synergique de ce flux. Ils se contentent tout simplement de les mettre en relation.

En effet, le réseautage est une activité importante pour l'établissement de liens d'affaires entre parties prenantes. Une manière de tisser un réseau est d'utiliser les réseaux sociaux en tant que catalyseurs (voir chapitre 3) et de créer un espace virtuel pour générer des relations de coopération gagnant-gagnant. Ce catalyseur peut jouer le rôle des éco-parcs industriels virtuels (Lowe, 1997). Walker, Kogut, & Shan (1997) and Tsai & Ghoshal (1998) soutiennent qu'il serait en effet bénéfique pour les entreprises qu'elles soient intégrées dans des réseaux sociaux denses qui favorisent entre autres la confiance. Ceci peut favoriser à son tour le réseautage, l'identification de synergies, et éventuellement le développement de la symbiose industrielle et son processus dynamique (Boons, Spekkink, & Jiao, 2014).

2.3 Les outils de la symbiose industrielle

Depuis que des préoccupations ont été soulevées sur le fait que l'écologie industrielle manque d'une présence en ligne et existe principalement comme une communauté hors ligne (Hertwich, 2007), des progrès ont été réalisés grâce aux nouvelles technologies de l'information et de communication (Grant, Seager, Massard, & Nies, 2010) et de diverses méthodes de collaboration à travers le web. Un ensemble d'outils en ligne ont ainsi vu le jour, incluant eiolca.net, nispnetwork. E-Symbiosis, Stocks and Flows (STAF) Project, GoodGuide.com, AMEE.com, sunetwork.it, la Bourse des résidus industriels du Québec (BRIQ), et Western Cape Industrial Symbiosis Programme (WISP).

Un des moyens utilisés pour faciliter la recherche et la communication entre les personnes concernées et intéressées par le concept de symbiose industrielle s'est avéré être un wiki avec EIPWiki (http://ie.tudelft.nl). Le but de ce wiki était de générer une base de données dynamique de symbiose industrielle à travers le monde afin de faciliter la recherche et la communication entre les personnes concernées et intéressées par la SI.

Plus récemment, le web sémantique a été identifié comme solution possible à l'initiation et à la promotion de la symbiose industrielle (Trokanas, Cecelja, & Raafat, 2014; Cecelja, et al., 2015). Le Web sémantique fait référence à l'évolution du World Wide Web vers le Web de données, où les données sont présentées avec une sémantique bien définie (Berners-Lee, Hendler, & Lassila, 2001). Un ensemble de technologies, des outils et des normes telles que RDF (Resource Description Framework), SPARQL (protocole SPARQL et RDF Query Language) et OWL (Web Ontology Language) forment les éléments constitutifs de cette vision améliorée du Web (Breslin, Passant, & Decker, 2009). En se basant sur la modélisation des connaissances et des ontologies comme moyen de modéliser les connaissances tacites et explicites (Gruber, 1995), la sémantique définit explicitement les données existantes, rendant ainsi les données machines traitables et prêtes pour faire de l'inférence automatisée. Ainsi, Davis, Chmieliauskas, & Nikolic (2014) and Nooij (2014) présentent Enipedia comme étant un wiki sémantique permettant de créer un environnement de discussion collaboratif, tout en fournissant des moyens pour que les données provenant de différentes sources soient connectées, interrogées et visualisées à travers différentes perspectives. Trokanas, Raafat, Cecelja, & Kokossis (2013), Trokanas, Cecelja, & Raafat (2014), et Trokanas, Cecelja, & Raafat (2015) présentent une approche sémantique pour l'appariement d'entrée / sortie de matières ou d'énergie. Ce service a été mis en œuvre en tant que service Web automatisé (Cecelja, et al., 2015).

En combinant les données structurées et non structurées tirées de nombreux sites à travers Internet, le Web sémantique pourrait ainsi fournir un substrat pour la découverte de nouvelles connaissances qui ne figurent pas dans une seule source d'information, et des solutions à des problèmes qui ne sont pas prévus par les créateurs de sites Web (Gruber, 2007).

Par ailleurs, les services de réseautage social ou le web social (développé au Chapitre 3), aussi appelés Web 2.0 ou médias sociaux, tels que les blogs, les wikis, les réseaux sociaux, flux RSS, des services de partage, des outils de marquage, sont des applications Web permettant aux utilisateurs d'interagir et de créer et de partager des données sur le Web (Mika & Greaves, 2008 ; Halpin & Tuffield, 2010).

Bien que ces applications affichent d'énormes quantités de contributions d'utilisateurs, ces dernières ne sont souvent disponibles qu'au niveau de l'application elle même, qui comporte des données massives, mais verrouillées, empêchant ainsi l'intégration des données et des connaissances partagées. Afin de permettre l'interopérabilité des données et la mise en œuvre de systèmes de connaissances collectives, le Web social peut bénéficier du Web sémantique pour définir explicitement la structure et la signification des données et des connaissances. Cela pourrait, à son tour, faciliter le partage et l'intégration de la connaissance collective à travers diverses applications sociales (Breslin, Passant, & Decker, 2009; Jovanovic, Gasevic, & Devedzic, 2009).

Le potentiel apporté par le web sémantique aux médias sociaux a encouragé de nombreux chercheurs et a abouti à un nouveau paradigme appelé le Web sémantique social (Yeung, Liccardi, Lu, Seneviratne, & Berners-Lee, 2009; Breslin, Passant, & Decker, 2009; Blumauer & Pellegrini, 2009; Jeremic, Jovanovic, & Gasevic, 2011). Dans la cadre de cette these, nous considérons que ce paradigme pourrait être utile au développement des symbioses industrielles dans la mesure ou il permet d'organiser les connaissances de l'industrie au sein d'un réseau social, en mettant à profit les technologies du Web sémantique pour promouvoir la collaboration et l'interoperabilité entre les données d'utilisateur lisibles et compréhensibles par une machine. La structure sémantique apportée par le Web sémantique et la connectivité sociale apportée par le Web social permettent au Web d'être plus ouvert (Breslin, Passant, & Decker, 2009). Il est à noter que le Web sémantique social a été adopté comme une plateforme d'apprentissage (Jovanovic, Gasevic, & Devedzic, 2009; Torniai, Jovanovic, Gasevic, Bateman, & Hatala, 2008; Jeremic, Jovanovic, & Gasevic, 2013) dans le but de décrire les scénarios d'apprentissage soutenus et améliorés par les technologies de Web sémantique social.

2.4 La modélisation à base d'agents en symbiose industrielle

La modélisation à base d'agents (MABA) est une approche *bottom-up* capable de décrire un système complexe comme celui de la symbiose industrielle. Il s'agit d'une approche pour modéliser le comportement des agents autonomes, en l'occurrence les entreprises dans le cadre des symbioses industrielles, et leurs interactions potentielles, qui conduisent à des comportements collectifs émergents. C'est donc un outil pertinent pour l'étudier et analyser les systèmes complexes (Gilbert & Troitzsch, 2005; Miller & Page, 2007). La modélisation à base d'agents est ainsi une approche qui étudie explicitement les phénomènes émergents au niveau macro (symbiose industrielle) à partir des interactions entre agents autonomes au niveau micro (synergies industrielles).

La MABA est constituée d'un ensemble d'agents pouvant avoir leurs propres caractéristiques et comportements et interagissant les uns avec les autres à travers la définition des règles appropriées (Crooks & Heppenstall, 2012) dans un environnement donné (Barnes & Chu, 2010). Elle nous offre ainsi la capacité de modéliser et simuler la façon dont les agents changent et interagissent dans le temps (Crooks & Hailegiorgis, 2014). Wooldridge & Jennings (1995) résument les caractéristiques des agents comme étant : autonomes ; sociale avec les autres agents ; réactif à des changements de leur environnement ; et proactif quant à leur capacité de planifier leur propre action pour atteindre des buts. Jennings, Sycara, & Wooldridge (1998) décrivent l’agent comme suit : « *Un agent est un système informatique, situé dans un certain environnement, qui est capable d'agir de manière autonome afin d’atteindre ses objectifs de conception*. » Ces caractéristiques des agents sont aussi soulignées par Macal & North (2008).

Étant donné que notre objectif est de comprendre un système complexe, c’est-à-dire la symbiose industrielle, les systèmes de modélisation à base d’agents sont appropriés, notamment pour étudier l’impact de certains facteurs dans la mesure où les processus et les interactions peuvent être explorés par la simulation (Kelly, et al., 2013). Ainsi, l’utilisation de la MABA dans le contexte de la symbiose industrielle revêt une utilité particulière. Tout d’abord, par le biais de cette approche, nous pouvons anticiper et explorer différents scénarios, les expérimenter, configurer des paramètres de décision et analyser les effets de ces changements (Axelrod, 1997). La MABA permet de modéliser les comportements adaptatifs et hétérogènes des composants du système (Balbi & Giupponi, 2009).

Ainsi, les symbioses industrielles sont également composées d'agents (entreprises, gouvernement, facilitateurs) interagissant entre eux, et présentant des propriétés émergentes qui ne peuvent pas être déduites simplement en agrégeant les propriétés des agents (Axelrod & Tesfatsion, 2006). En outre, les symbioses industrielles sont un phénomène émergent et en partie ou entièrement un système auto-organisé dont l'évolution est fonction des interactions complexes entre de multiples organisations poursuivant des objectifs individuels (Bonabeau, 2002).

Les symbioses industrielles sont un système complexe puisqu'elles comportent des aspects sociaux et humains ainsi que des interactions spatiales et temporelles entre les différentes parties prenantes. Le potentiel que la simulation à base d'agents offre à l'étude des symbioses industrielles et aux éco-parcs industriels a été déjà discuté par certains chercheurs (Axtell, Andrews, & Small, 2001; Kraines & Wallace, 2006). Cependant, il y a eu depuis, peu de recherche sur les modèles à base d'agents appliqués à la symbiose industrielle. Les chercheurs au sein de la communauté de symbiose industrielle ont proposé des applications de la MABA, dans lesquelles les agents mis en œuvre sont des entreprises individuelles avec un comportement individuel et un objectif économique et écologique (Cao et al,, 2009; Bichraoui, Guillaume, & Halog, 2013; Romero & Ruiz, 2014; Albino, Fraccascia, & Giannoccaro, 2016). Cao et al., 2009 ont utilisé un système de modélisation où les entités d'un parc sont des agents usine, consommant et produisant des résidus, et ayant un impact environnemental. Ils ont effectué des simulations basées sur un système de prix, dans lequel des agents environnementaux pouvaient imposer des pénalités si leur capacité était dépassée. Kim et al. (2012) ont proposé à leur tour une modélisation à base d'agents pour un réseau de réutilisation des eaux usées dans un parc écoindustriel. Bichraoui, Guillaume, & Halog (2013) ont élaboré un MABA pour étudier les effets potentiels des facteurs culturels et comportementaux. Romero et Ruiz affirment qu'une approche de modélisation pour les parcs éco-industriels doit tenir compte de différents types d'évaluation des scénarios alternatifs ou des comportements individuels (Romero & Ruiz, 2014).

Albino, Carbonara, & Giannoccaro (2006) présentent un modèle à base d'agents pour étudier l'effet sur l'innovation dans un quartier inter-organisé industriel avec une gamme homogène de produits. Plus tard, Albino, Fraccascia, & Giannoccaro (2016) ont utilisé la simulation à base d'agents pour modéliser le comportement des acteurs du réseau symbiotique. Jian et Zengqiang (2009) ont identifié quant à eux des éléments clés dans le développement d'un parc éco-industriel. Il est à noter que deux méthodes d'évaluation ont été intégrées à la MABA, soit l'analyse des flux de matières (AFM) (Knoeri, Wäger, Stamp, Althaus, & Weil, 2013) et l'analyse du cycle de vie (ACV) (Davis, Nikolic, & Dijkema, 2009) afin de simuler le comportement et l'interaction des entreprises et leurs impacts sur les flux de matières et le cycle de vie des produits.

2.5 Synthèse de la littérature

À la lumière de cette revue de littérature, il est important de mentionner que différents points de vue ont été développés sur la dimension sociale de la symbiose industrielle, mais que peu de tentatives ont été faites pour systématiser ces idées dans un cadre conceptuel plus global qui nous permet de savoir comment mettre en évidence de telles relations pour initier des opportunités de synergies. La contribution que nous cherchons à faire à travers cette thèse est la création d'un cadre de travail qui exploite le potentiel du web sémantique social afin de favoriser la collaboration et le partage de connaissances et d'informations entre les membres des communautés industrielles en ligne. Ce cadre adopte les concepts de Linked Open Data (LOD) qui permettent le partage et l'échange d'informations avec des systèmes externes. Cette caractéristique distingue le cadre proposé des approches existantes à l'initiation des synergies industrielles.

La deuxième contribution que ce travail cherche à apporter est de créer un modèle à base d'agents qui inclut les notions de confiance, les liens sociaux et le partage de connaissances afin d’illustrer l’impact de la structure et de la dynamique sociale sur la formation de symbioses industrielles. Ainsi, le fait d’étudier l’impact de différentes configurations d'environnements sociaux (structure du réseau et intensité des relations sociales) sur la création de synergies industrielles constituera un outil de recherche pour la poursuite de l'avancement théorique dans ce domaine.

Ainsi, cette thèse à pour but de contribuer à répondre à la question émanent de cette réflexion :

> Comment (a) initier la découverte et mise en œuvre des opportunités de synergies industrielles, et plus particulièrement (b) coordonner les actions et les interactions des acteurs des systèmes industriels pour supporter le partage des informations ?

Tout au long des prochains chapitres, il s'agit de démontrer qu’à l’aide de l’approche conceptuelle du Green Social Networking, d’une ouverture sur le web et à travers une illustration d’aide de la simulation à base d’agents, un réseau social avec des fonctions de partage et d’échange pourrait contribuer à initier la création de synergies à court terme et aboutir probablement à des symbioses industrielles à long terme.

CHAPITRE 3 MÉTHODOLOGIE DE RECHERCHE ET STRUCTURE DE LA THÈSE

Dans ce chapitre, nous présentons la démarche méthodologique générale de l'ensemble du travail de recherche, ainsi que l'organisation générale du document afin de clarifier la cohérence de chaque contribution par rapport aux objectifs de la recherche.

3.1 Ojectifs spécifiques de la recherche

Cette section rappelle les objectifs spécifiques de la recherche introduits au Chapitre 1 afin de répondre à la question de recherche proposée.

- **Objectif #1** : Proposer un cadre conceptuel décrivant le rôle potentiel des réseaux sociaux pour initier et mettre en œuvre les opportunités de synergies industrielles.
- **Objectif #2** : Proposer un outil permettant de faciliter l'échange d'informations entre partenaires potentiels et la découverte d'opportunités de synergies industrielles.
- **Objectif #3** : Proposer un cadre et un outil permettant d'évaluer l'impact de la dynamique et de la structure des échanges d'informations au sein d'un réseau social d'un groupe d'entreprises sur l'initiation de synergies industrielles.

Le premier objectif spécifique de ce travail de recherche permet de positionner conceptuellement, mais aussi dans l'état actuel de développement technologique des réseaux sociaux, quelles sont les contributions potentielles de ces technologies pour initier et mettre en œuvre des synergies industrielles. Ce travail est notamment nécessaire à la conception d'une plateforme de média social pour supporter le développement de réseaux sociaux verts.

Le second objectif spécifique est plus précis puisqu'il permet plus particulièrement de développer un outil utilisable dans le cadre d'une plateforme de média social, et dédié à l'identification de synergies industrielles potentielles afin de connecter les entreprises. Ainsi, au-delà de la création d'une communauté d'échange et de partage d'information, cet outil a pour but de supporter directement l'identification des partenariats d'affaires potentiels qui, comme il est discuté au Chapitre 4, est l'étape clef du développement des synergies industrielles.

Le troisième objectif est complémentaire aux deux premiers dans la mesure ou il permet de développer un outil méthodologique permettant d'étudier de façon théorique comment la dynamique et la structure des réseaux sociaux au sein de groupes d'entreprises, notamment en termes de création de nouveaux liens sociaux et de type de structure de réseaux, affectent la création de synergies industrielles, et ainsi le développement de symbioses industrielles.

Afin d'atteindre ces objectifs spécifiques, il a été nécessaire de mettre en œuvre plusieurs méthodes de recherche complémentaires et multidisciplinaires en écologie industrielle, système d'information et simulation à base d'agents. La section suivante présente rapidement ces approches méthodologiques.

3.2 Approche méthodologie multidisciplinaire de la recherche

Cette section décrit succinctement pour chaque objectif, la méthodologie de la recherche utilisée.

Objectif #1 : proposer un cadre conceptuel décrivant le rôle potentiel des réseaux sociaux pour initier et mettre en œuvre les opportunités de synergies industrielles.

Autrement dit, il s'agit d'étudier comment les outils et fonctions des médias sociaux peuvent contribuer à initier des synergies industrielles. Plus spécifiquement, il s'agit de proposer un cadre conceptuel basé sur l'analyse de la littérature permettant de circonscrire les contributions potentielles des réseaux sociaux au développement des synergies industrielles. Pour cela, plusieurs analyses de la littérature ont été réalisées. La première analyse consiste à étudier la littérature décrivant les processus de développement des synergies industrielles et les facteurs contribuant à ce développement. Ensuite, une seconde analyse systématique de la littérature des fonctions existantes des plateformes de médias sociaux est réalisée afin de considérer leurs contributions potentielles à ces processus de développement.

La mise en œuvre de cette approche méthodologique et les résultats ont été publié dans la revue *Journal of Cleaner Production* et sont présentés au Chapitre 4.

> **Ghali, M.R.**, Frayret, J.-M., Robert, J.-M., 2016. Green social networking: Concept and Potential Applications to Initiate Industrial Synergies. *Journal of Cleaner Production*. 115(1), pp. 23–35.

<u>Objectif #2</u> : Proposer un outil permettant de faciliter l'échange d'informations entre partenaires potentiels et la découverte d'opportunités de synergies industrielles:

Autrement dit, il s'agit d'adapter et de développer des fonctions des médias sociaux pour permettre d'initier des synergies industrielles. Afin d'atteindre cet objectif, plusieurs travaux ont été réalisés. Premièrement, nous avons conçu et développé un plateforme prototype de réseau social pour le Centre de Transfert Technologique en Écologie Industrielle (CTTEI), partenaire de ce projet. Ce travail, validé avec le partenaire, n'est cependant pas rapporté dans cette thèse, car ce n'est pas un travail de recherche. Il s'agit plutôt de développement informatique réalisé dans le cadre du partenariat, mais dont les enseignements ont contribué à comprendre à la fois l'écologie industrielle et la pertinence des médias sociaux au développement des synergies industrielles.

Deuxièmement, une analyse de la littérature relative aux outils et systèmes d'information existants et dédiée à l'écologie industrielle est effectuée. Ces systèmes supportent généralement l'échange d'informations dans le domaine général de l'écologie industrielle, et plus particulièrement dans le domaine des symbioses industrielles. Ensuite, nous proposons de concevoir et de développer une approche ouverte basée sur le web sémantique pour faciliter l'identification de partenaires potentiels et leur échange d'informations, afin de faciliter l'initiation d'opportunités de synergies industrielles. Nous proposons aussi d'effectuer une preuve de concept de l'approche proposée.

La mise en œuvre de cette approche méthodologique et les résultats ont été soumis à la revue *Computers & Chemical Engineering* et sont présentés au Chapitre 5.

> **Ghali, M.R.**, Frayret, J.-M., 2016. Social Semantic Web Framework for Industrial Synergies Initiation. Submitted to *Computers & Chemical Engineering*.

<u>Objectif #3</u> : Proposer un cadre et un outil permettant d'évaluer l'impact de la dynamique et de la structure des échanges d'informations au sein d'un réseau social d'un groupe d'entreprises sur l'initiation de synergies industrielles:

Autrement dit, cet objectif permet de développer un outil pour anticiper l'impact de la structure et de la dynamique sociales sur l'échange d'informations, et ultimement sur l'initiation de synergies industrielles. Afin d'atteindre cet objectif, nous proposons d'analyser la littérature portant sur les facteurs sociaux affectant le développement des synergies industrielles, ainsi que les modèles de simulation du développement des symbioses industrielles. Ce dernier domaine est très récent et peu de modèles de simulation ont été proposés jusqu'à maintenant. Ensuite, nous proposons de développer un modèle de simulation à bases d'agents permettant de simuler la dynamique des échanges d'informations et du partage de connaissances au sein des réseaux sociaux pouvant exister au sein de groupes d'entreprises industrielles, et d'étudier l'impact de ces échanges sur le développement des synergies industrielles. Ensuite, ce modèle est implémenté dans un outil de simulation (NetLogo), et testé et validé de façon non-spécifique en fonction des observations empiriques générales. Enfin, nous proposons d'étudier l'impact de divers scénarios de structure et de dynamique sociales sur le développement de synergies industrielles.

La mise en œuvre de cette approche méthodologique et les résultats ont été soumis dans la revue *Journal of Cleaner Production* et sont présentés au Chapitre 6.

> **Ghali, M.R.**, Frayret, J.-M., Ahabchane, C., 2017. Agent-Based Simulation of Industrial Symbiosis Evolution: Impact of Social Networks. Submitted to *Journal of Cleaner Production*.

CHAPITRE 4 ARTICLE 1 : GREEN SOCIAL NETWORKING: CONCEPT AND POTENTIAL APPLICATIONS TO INITIATE INDUSTRIAL SYNERGIES

Mohamed Raouf Ghali, Jean-Marc Frayret, Jean-Marc Robert

Journal of Cleaner Production

Abstract: This paper presents a conceptual analysis of computer-supported social networking and its potential applications for industrial ecology. More specifically, it introduces the concept of Green social networking (GSN), and analyzes the potential role of online social networking for stimulating social connections and enabling material flow compatibilities in a way that can lead to the formation of industrial synergies. Thus, this paper proposes a review of the role of social media and social networks in order to analyze their ability to stimulate the initiation of industrial synergies. This analysis provides a framework for creating a Web-based industrial synergy support system based on social network-style functionality. For industrial companies and their key stakeholders, this might serve as a system that helps forge partnerships and connections with like-minded others, and ultimately helps discover material flow compatibilities. It could also help post and distribute related information for an entire industry, which could improve the dissemination of knowledge related to industrial ecology. Finally, GSN could provide researchers interested in exploring the potential of social networks with a new and rich research domain, while bridging both online and offline connections between personal and business sectors.

Keywords: Industrial synergy; Industrial symbiosis; Sustainable development; Social media; social network; Green social networking.

4.1 Introduction

For most people, social networks refer to Facebook, Viadeo, LinkedIn and similar sites or applications whose purpose is to connect people online. These new mediums of communication are defined by collaboration and sharing. From an operational standpoint, industrial ecology deals with closing the loop of material and energy waste flows. It is materialized through the network use and management of resources and wastes. Therefore, industrial ecology relies on the creation and sharing of information about industrial flows between economic actors within a shared territory.

Through the exchange and use of waste materials and by-products, industrial synergies increase the level of interaction between industries (Mohammed, Biswas, Yao, & Tadé, 2013). For the purposes of this paper, industrial synergy will be considered as a form of eco-collaboration between two or more companies. More specifically, this paper generally considers industrial synergies as the substitution, sharing, and/or treatment of material and energy waste flows between companies, regardless of the nature of such a flow (i.e., mutualistic or commensal) (Jensen, Basson, Hellawell, Bailey, & Leach, 2011). A set of synergies within a territory is an industrial symbiosis. Industrial symbioses create and entail collaboration within clusters of firms based on the replicable behaviours and patterns of natural ecosystems, whereby wastes from one species become resources for another (Frosch & Gallopoulos, 1989).

The academic literature describes the concept of industrial symbiosis in many different shapes and forms. It is often associated with eco-industrial parks (EIP), eco-industrial developments, regional industrial sources and concurrent synergies, circular economies, and eco-industrial networking (Côté & Cohen-Rosenthal, 1998; Cohen-Rosenthal & Musnikow, 2003; Van Beers, Corder, Bossilkov, & Van Berkel, 2007; Geng & Doberstein, 2008; Cardinal Group, 2013). More specifically, an industrial symbiosis entails an industrial network, which can generally be developed either spontaneously (Chertow, 2000; Jacobsen, 2006) or through planning (Chertow, 2007), regardless of its structure (Chertow, Ashton, & J.C., 2008). Such networks achieve environmental goals and contribute to environmental sustainability. However, economic incentives are the primary motivation for organizations involved in the creation of environmental benefits (Côté & Cohen-Rosenthal, 1998; Desrochers, 2004; Chertow M. R., 2007; Duflou, et al., 2012). Exchanges between organizations are not restricted to material and energy flow; they can also contain information and ideas about business practices (Mirata & Emtairah, 2005). Such intangible exchanges are essential for companies in finding suitable business partners and sharing resources within a business community (Heeres, Vermeulen, & de Walle, 2004).

The definition of industrial symbiosis by (Lombardi & Laybourn, 2012, p. 31) shares similarities with that described by (Watson, Boudreau, & Chen, 2010): “[engaging] diverse organisms in a network to foster eco-innovation and long-term cultural change. Creating and sharing knowledge through networks yields mutually beneficial transactions for novel sourcing of required inputs, value-added products destinations for non-outputs, and improved business and technical processes." More specifically, this definition emphasizes the importance of knowledge sharing in the context of eco-innovation and mutual benefits, thus highlighting the social nature of industrial symbiosis as composed of nodes and relationships between members.

Based on the findings of (Lombardi & Laybourn, 2012), this paper explores the role of social networking and its importance for the process of creating industrial symbiosis. The objective of this paper is not to propose or introduce a new information system (e.g., BRIQ, Presteo) or a semantic tool (e.g., enipedia, e-symbiosis); rather, the aim is to investigate and illustrate the potential role of social media and social networks throughout the collaborative process of sharing knowledge and information among different members of online communities of industries, organizations, and institutions. This role is afforded by the new concept of Green social networking (GSN). As such, the objective of this paper is to analyze the potential role GSN could have in creating industrial synergies and industrial symbioses.

4.2 Basic Concepts, Objectives, and Methodology

In order to clarify the distinction between social media and online social networks, this section first presents general definitions and illustrations of these two concepts. A new definition of social media is then proposed. Next, the general methodology of this conceptual analysis is presented.

4.2.1 Social media vs. social networks

(Kaplan & Haenlein, 2010, p. 61) define social media as "*a group of Internet-based applications that build on the ideological and technological foundations of Web 2.0, and that allow the creation and exchange of User Generated Content*." This definition places the focus on users who generate content. In a similar manner, (Kietzmann, Hermkens, McCarthy, & Silvestre, 2011, p. 241) provide a definition that emphasizes the interactive nature of such platforms: "*social media employ mobile and web-based technologies to create highly interactive platforms via which individuals and communities share, co-create, discuss, and modify user-generated content*."

Examples of social media include blogs, multimedia sharing sites (e.g., Flickr and Instagram for images; YouTube and Dailymotion for videos), collaborative projects (e.g., Basecamp, Chatter, Google docs), bookmarking sites (e.g., Pinterest, Digg), reviews and user assessments (e.g., Yelp, Foursquare, etc.), and social networking sites, among many others. Every site, application platform, or type of software has its own business model. For instance, Foursquare is a social network that allows users to geo-tag directly from their mobile device to show friends their location, recommend places, and share them on Facebook or Twitter. Like many emerging companies, the Foursquare business model is constantly evolving. For instance, it recently split its business into two separate applications. One application aims to highlight places to discover and proposes a customized search function based on user interests, while the other aims to perform check-in (e.g., automatic geo-localisation, detecting false check-in, asking for third-party verification). Hence, social media are better defined by their social functions than their constantly evolving business model.

In line with the definitions of (Kaplan & Haenlein, 2010) and (Kietzmann, Hermkens, McCarthy, & Silvestre, 2011), and because their business models are adapting and evolving, we define social media *as Web-based tools with social functions available to Web publishers and/or site owners, which are run by a community through a desktop or a mobile interface*. In more practical terms, it is a technology with well-defined recreational and social functions whose operations are fuelled by various data (e.g., images, video, text) being shared or exchanged. This definition primarily emphasizes the communication technology (i.e., exchange and sharing) and informational aspects (i.e., data), which thereby contribute to forming social communities.

Similarly, a social network refers to social connections and interconnections between users with the potential to reach individuals. In other words, a social network takes the relationship between individuals as fundamental to its purpose, like Facebook or LinkedIn. The term social media thus refers to the online platforms that enable all communications and information exchanges that take place within, or outside of, online social networks. Therefore, we define a social network as an application of social media, the primary focus of which is on users' social connection and networking. Social networks can include other social media functions in order to extend their primary focus and provide users with complementary services. In other words, a social network is a form of social media that is primarily focused on networking, but a social media is not necessarily a social network. Consequently, not all of the aforementioned examples are social networks. For instance, blogs aim primarily to publish content (e.g., case study, opinion, news). YouTube or Flickr aims to promote the sharing of videos or photos, respectively. Networking is only an addition to these functions, and it is not always the primary goal of a social media platform. In this paper, the term “Social Media” refers to any kind of social media platform, including social networks. However, the term “Social Network” refers exclusively to social media platforms whose primary aim is networking.

4.2.2 General methodology and objective

This paper first reviews different models of industrial symbiosis development. It then presents an analysis of existing Information Systems dedicated to Industrial Symbiosis. In particular, it examines why these systems are not designed to stimulate social interactions and the emergence (i.e., spontaneous formation) of industrial synergies. Next, based on the analysis and systematic review of current social media platforms and their functions, this paper proposes a definition of the new concept of Green social networking as a novel Information System application, which could lead to the promotion and development of cleaner industrial practices in industrial networks. This paper also includes a broad analysis of the primary (e.g., sharing, collaboration) and secondary (e.g., advertising, linking) functions of social media with respect to their potential impact on the formation of industrial synergies.

4.3 Industrial Symbiosis

The academic literature on industrial symbiosis presents many case studies dealing with existing industrial networks around the world. This includes industrial areas such as Kwinana in Australia (Van Beers, Corder, Bossilkov, & Van Berkel, 2007), the Rotterdam Harbor and its industrial complex in the Netherlands (Baas & Boons, 2007), and the US territory of Puerto Rico (Chertow & Lombardi, 2005). Among these, Kalundborg in Denmark is the most cited and emblematic example of industrial symbiosis (Jacobsen, 2006). In general, this literature uses case study to better understand how industrial symbioses work and develop. From these studies, different industrial symbiosis development models have emerged.

4.3.1 Industrial Symbiosis development models

Researchers describe the concepts of industrial synergy and industrial symbiosis extensively, noting that the initiation and development of industrial symbiosis over time typically corresponds to one of two development models (Chertow M. R, 2007): a self-organized (i.e., serendipitous) model or a planned (i.e., goal-directed) model. Investigations and comparisons of these two models and their respective successes, failures, and limiting factors have given rise to debates. For instance, (Lombardi & Laybourn, 2012) revisited the initial definition of industrial symbiosis proposed by (Chertow, 2000), and denied the argument that geographical proximity was a key element for planned attempts at developing industrial synergy. These authors consider these factors as neither necessary nor sufficient for the development of industrial symbiosis.

Recent studies suggest a third development model that involves the facilitated formation of industrial symbiosis by organizations or individuals (Paquin & Howard-Grenville, 2012). This model implies the active role of a third party at various steps of the development, and covers the spectrum between pure self-organization (i.e., serendipitous) and pure planned development (i.e., goal-directed). The authors explain that as the facilitator gains expertise and experience, this development process becomes more goal-directed.

Beyond the need to understand contributing factors for the emergence of industrial symbiosis (i.e., self-organized, facilitated, or planned), the need to better understand the initiation phase of this development is particularly relevant. Indeed, during this phase, the potential partners do not initially have sufficient information about each other. This is precisely the type of situation in which an active facilitator/coordinator or a social media, such as a social network, could play a significant part.

From a general standpoint, self-organization refers to the processes through which an organizational structure emerges on its own, without being led or shaped by an outside source. Although a facilitator may play a role in connecting people and organizations, self-organization is mainly a serendipitous process. In business management theory, the existence of self-organized communities consisting of companies that share interests, protocols, and infrastructure is well documented (Miles, Snow, Fjeldstad, Miles, & Lettl, 2010). Their practices support collaboration among members. Self-organized communities manifest themselves in various ways and circumstances — for instance, to revitalize the economy of a community, to create joint ventures, and to achieve common goals for mutual gain, or to solve an environmental issue through an industrial symbiosis (Brooks, Wang, & Sarker, 2012).

Beyond the need to study the development of the symbiotic business community, it is necessary to study the development of a single industrial synergy between two businesses. A simple exchange consists in the establishment of a link between two companies in which both are aware of the benefits of their cooperation. The development of such a link can in turn affect other companies and stakeholders (Meneghetti & Nardin, 2012). For example, the synergy and symbiosis projects conducted by the Centre de Transfert Technologique en Écologie Industrielle (CTTEI) show that when a company has developed a synergy, it also develops the capability to move forward with other similar initiatives and create further opportunities for symbiotic development.

On the one hand, in order for industrial synergies to emerge, stakeholders must know each other, develop trust over time (Gibbs, 2003; Mirata, 2004; Sakr, Baas, El-Haggar, & Huisingh, 2011), and reduce the mental or psychological distance between them (Jensen, Basson, Hellawell, Bailey, & Leach, 2011). This paper argues that social networks could play a role to connect organizations and eventually bridge the gap between them. On the other hand, facilitated and planned industrial symbiosis, whereby potential synergies are identified and initiated by a third party, require the use of a structured approach (e.g., COMETHE) and Information Systems, as outlined in the next section.

4.3.2 Industrial Symbiosis development models

Several information systems have been developed over the years in order to support the development of industrial symbiosis. These tools include the following:

- The Facility Synergy Tool (FAST), developed by the US-EPA, which is an access database connected to a geographic information system (GIS);
- Prestéo (Système durables), a Web-based tool with limited (non-public) access, which incorporates a database of industrial flows in order to support the exchange of industrial flows and the identification of synergies;

- The ISIS (Industrie et Synergies Inter-Sectorielles) database, developed by the EDF (Électricité Réseau Distribution France) group; it only takes physicochemical aspects of flows into consideration;
- SYNERGie, a system developed by the UK-based NISP (National Industrial Symbiosis Program); the system was developed as a support tool for facilitating industrial symbiosis programs within business communities; it is only accessible to the system's facilitators;
- The ISDATA project (Industrial Symbiosis Data Sources), which aims to structure data relevant to industrial symbiosis into one central repository.
- Enipedia explores the applications of wikis as well as the potential for energy and industry issues on the semantic Web;
- E-Symbiosis is a knowledge-based service that aims to promote, demonstrate, and advance Industrial Symbiosis for the industry, including commercial trading of material (Cecelja, et al., 2015).

These tools can help companies or third-party industrial symbiosis planners and facilitators exploit potential industrial synergies in various ways. These include best practice and case studies presentation and by-product compatibilities analysis.

More specifically, these tools aim to provide, on the one hand, functions such as saving, storing, transforming, and publishing data (i.e., input characteristics) from one or several sources. On the other hand, they aim to provide functions to transmit this data to one or several destinations. Such tools allow companies to monitor specific production indicators, which in turn enable them to carry out simple data analysis. Some of these tools also embed specific knowledge, or simulation or mathematical models and indicators (e.g., impact indicators, environmental footprints, cost models, flow models). They can also exploit the knowledge of past analysis, impact studies, and best practices in order to provide impact and performance estimations, forecasts, or recommendations. Such tools are necessary to assess the cost/impact trade-off of industrial synergy, as well as to ascertain the most cost-effective configurations. Some of these tools address issues related to semantic and data modelling in order to enable information sharing between organizations across regions and countries (Grant, Seager, Massard, & Nies, 2010). For example, Enipedia has an ontological representation of industrial symbiosis case studies (Davis, 2012), and e-Symbiosis has a semantic description of resources and processing technologies (Raafat, Trokanas, Cecelja, & Bimi, 2013; Trokanas, Cecelja, & Raafat, 2014). However, ontological representations of resources are difficult to establish and maintain, especially because of the semantic annotation process. For example, in a single material subcategory (e.g., rubber) there are many uses and applications for which the semantic annotation process requires the contribution of industrial and chemical experts.

(Grant, Seager, Massard, & Nies, 2010) examined several early industrial symbiosis tools. These tools were developed between 1995 and 2000 and aimed to identify synergies in the context of industrial clusters. The author found that these tools suffered from high start-up costs. They were also generally too complex, as they required a high level of user involvement and systems knowledge. Furthermore, they were not designed to facilitate actual cooperation or integration between potential business partners. Their specific objective was only to support the identification of potential industrial synergies. They were often based on a Geographic Information System (GIS), which stores and retrieves information to find resources (e.g., wastes, by-products) based either on geographical proximity or the premise of searching through a directory with a structured list of classified resources.

These information systems for industrial symbiosis were mainly used to characterize and analyze the flow of materials and energy (i.e., the industrial metabolism) in an industrial system. In other words, they can assist in the search for synergy opportunity, but their access is generally limited to specific users through an online portal or license. These types of applications are part of a new class of Information System applications dedicated to solving environmental issues. They are referred to as Environmental Informatics (Pillmann, Geiger, & Voigt, 2006; Isenmann & Chernykh, 2009). Even if they are used for green purposes, these tools do not focus on active participation and communication among users. To our knowledge, the applications do not include any social media functions (see Section 3.5 for a presentation of these functions).

In addition, we argue in this paper that there is an overlap between certain elements of industrial symbiosis (i.e., organizations, network, creating, sharing, and exploiting knowledge) and certain components usually found on social networking sites (i.e., social actors, profiles, social relations, and content). As highlighted by (Dijkema & Basson, 2009), industrial (i.e., technical) and social communities (i.e., offline social networks) are mutually influencing and co-evolving complex systems that ultimately play a role in shaping the development of industrial symbiosis. Furthermore, social behaviour and relationships are involved in the creation and exchange of information necessary to the development of industrial symbiosis. Social ties help build the social capital of managers and promote the formation of social norms that contribute to the regulation of trade.

In summary, existing computer-supported tools for industrial symbiosis are generally characterized by the following capabilities and functions:

- Standard or GIS-based data storage and processing (semantic data storage and processing are just emerging);
- Data publishing and transmission (mostly non-public);
- Data monitoring and analysis ;
- Flow matching based on by-product compatibilities and geographic proximity; and
- Decision support in the form of recommendations based on historical data, best practices, and cost estimation.

However, they are mostly designed to be used by a third party, as they are too complex, not user-friendly, or simply not designed to be used by companies. In other words, except for the e-Symbiosis platform, they are not designed to facilitate the active participation, exchange, and interaction among companies and other users.

In conclusion, the similarities between industrial symbiosis and social networks, which both refer to the idea of creating connections between companies/individuals, and the lack of Information Systems dedicated to such functions, naturally raise the following question: can social media support the initiation and thus the development of industrial synergies and symbioses? This question is discussed in depth in the next section.

4.4 Current Role of Social Media

In order to analyze the potential role of social media and social networks in initiating the development of industrial synergies and symbioses, one must first differentiate between online and offline social networks. Online social networks are adaptations of traditional offline social networks, which consist of individuals and their relationships. Online social networks aim to facilitate consolidation among individuals with common interests without being hampered by geographical and social constraints. Individuals are either spontaneously or selectively grouped on the basis of common interests and shared values. The traditional offline network model is thus simply transposed to online social networks. In other words, they mimic their topology, evolution, and demographics (Wilson, 2008). In the context of industrial symbiosis, workshops or information events can be considered as offline social networking. Similarly, industrial symbiosis matchmaking workshops can help organizations explore new and innovative opportunities for recycling wasted resources and generate new business opportunities (Paquin & Howard-Grenville, 2012). For example, in Tianjin Economic-Technological Development Area (TEDA), one of the leading EIP projects in the programming of a circular economy in China, workshops are organized by TEDA Eco Center. Here, a coordinator plays an important role in the process of exposing companies to cutting-edge research by engaging participants in discussion, promoting knowledge exchange, and providing mentoring and networking opportunities.

Industrial Networks are often born from a network of personal contacts (i.e., people who work for different companies). By expanding these networks, both at the individual and corporate level, the chance of discovering synergistic opportunities increases. One way to expand a network of contacts is to create a group on a social network site such as LinkedIn. Another is to join already-existing groups. Such groups include thematic chat rooms, which often bring together experts on a specific field. These groups are generally used to exchange tips, provide feedback, and share thoughts on general and specific issues. They represent an opportunity to share knowledge and further develop current relationships. They also allow for the staging of a simple event or workshop, as well as the application of ideas proposed in discussions. Table 3.1 summarizes the differences between the two types of social networks.

(Ellison, Steinfield, & Lampe, 2007) noted that social networking sites are mainly used to maintain or solidify existing offline ties, while generally eschewing the creation of new ones and the opportunity to connect with strangers. Similarly, (Boyd, 2007) concluded that most social networking sites primarily support pre-existing social relations, choosing not to focus on the establishment of new ones.

Table 4-1: Offline social networks versus online social networks

	Offline social network through workshop, Industrial symbiosis events	***Online social network***
Access	Geographically Limited	Open to all
Information sharing	Limited	Information shared in real time
Dissemination and promotion of innovation	Limited in space and time. Physical or traditional media are necessary for communication (e.g., ppt presentation, pdf file etc.)	Unlimited, real-time news (e.g., tweets)
Influencers	Limited by their physical presence.	They use Web 2.0 tools to produce and disseminate relevant content; They join the interests of a community; and They regularly feed exchanges and discussions.

Generally, Industrial Synergies are inter-organizational (i.e., business-to-business or B2B) relationships that are similar to supply chain relationships (Egan, 2011). The role of social media in this B2B context is considered instrumental for the development of relationships among organizations (Enders, Hungenberg, Denker, & Mauch, 2008; Kaplan & Haenlein, 2010). In order to develop relationships, build trust, and identify prospective corporate and industrial partners, organizations can turn to Social Media, such as Facebook and LinkedIn, as a platform for initiating these processes (Shih, 2009). The theory of *embeddedness* (Granovetter 1985; Zukin & DiMaggio, 1990) posits that the economic actions of organizations are not just driven by their economic transactions, but are also conditioned by social mechanisms. In other words, Granovetter (1985, p. 487) uses the concept of "*embeddedness*" to describe the fact that human behaviours, which include economic behaviours, are "*embedded in concrete, ongoing systems of social relations*."

In order to analyze the role of social media in business, we first provide two examples showing the activity and growth of groups on social networks. The first example illustrates the use of social networks for the purposes of developing B2B relationships. Table 3.2 identifies several examples of such groups as well as their level of activities. Next, the second example illustrates the use of social media groups with general contribution to sustainable development, industrial symbiosis, and industrial ecology (see Table 3.3).

In order to delve further and more specifically into the potential role of social media and social networks in initiating industrial synergies, this paper presents a systematic analysis of four general roles of Social Media: (1) learning from each other; (2) information sharing; (3) relationship building; and (4) community coordination.

4.4.1 Learning from each other

One of the challenges in the development of industrial synergies lies in the promotion of the basic principles of industrial ecology. Beyond the need to efficiently manage the disposal of industrial waste, companies must first perceive their waste and by-products as potentially valuable assets and not as problems that must be dealt with. Hence, the sharing of good practices and experiences to be derived from industrial ecology can contribute positively to changing the perception these organizations have of their waste products. Social networking Sites have shown that they can serve as platforms for learning, in which members share explicit or implicit knowledge and learn from other members who are not necessarily in their own contacts. (Wheeler, Yeomans, & Wheeler, 2008) recommend the use of a social networking site as an alternative to Learning Management Systems.

Explicit knowledge is knowledge that can be transmitted without taking the risk that it will lose all or part of its meaning; in this respect, it can be codified. Although explicit, it also represents knowledge that members may have experienced and learned through practice over time.

Implicit (i.e., tacit) knowledge, as presented by (Grant, Seager, Massard, & Nies, 2010), refers to specialized know-how and cannot be codified, for example, through the communication and trust of conversant companies (Trokanas, Cecelja, & Raafat, 2014; Grant, Seager, Massard, & Nies, 2010; Gibbs, 2003). Collaborative learning expertise might create know-how and develop greater knowledge in the field by strengthening communications and interactions between related parties.

Because implicit knowledge is generally related to individual experience and personality, the use of a point of reference that aggregates many members and experts, such as a social network site, increases the likelihood that someone's personal experience might contribute to solving somebody else's problem. Online social networks can help instructors and learners within an online environment by presenting themselves socially in order to connect with one another (Lee & McLoughlin, 2010). In other words, social network sites allow their members to share their problems, solutions, and experiences. Therefore, they allow them to find solutions to problems for which other members have already found solutions. This kind of cooperation on social networks allows experts to diffuse their expertise and contribute to building their online reputation. It also supports passive (i.e., non-contributing) members to take advantage of exchanged knowledge by receiving an email or notification for each new discussion. Studies revealed that information and knowledge sharing is the essential motivation in social network services usage (Yang & Sageman, 2009). Knowledge sharing is also one of the main motivations to participate in social media such as Flickr (Nov, Naaman, & Ye, 2009). As mentioned earlier, there are many groups in different social network sites and social media in the domain of industrial ecology and symbiosis. Many of these groups are active in the academic domain. Table 3 presents a few of these grouped by platform, name, and subject. Posting articles, comments or answers to questions on such media allow users to demonstrate their expertise while promoting those of their companies.

4.4.2 Information sharing

Information differs from knowledge because it cannot be directly used as a basis for decision-making. It can take the form of observations, which have not necessarily been assimilated or formalized into knowledge. Information is the raw material of knowledge creation that can be used to make decisions and solve problems (Boisot & Canals, 2004). Like knowledge, information can be shared, stored, and retrieved in a collective manner, and then later consulted on web-based networks (Cavico, Mujtaba, Muffler, & Samuel, 2013). This process allows users to communicate, socialize, and even share documents, pictures, video, and audio files (Smith & Duggan, 2012).

Several examples found in the academic literature underline the distinction between knowledge and information. For instance, in the context of healthcare, (Boyer, 2011) pointed out the uses of social media spaces for exchanging and communicating information. By doing so, the author described ways in which people can use social media to share their concerns about medical diagnoses with geographically distant friends and family. Along the same lines, (Sharp, 2011) described the example of a clinic that adopted social media platforms to encourage the sharing of patient feedback. Instead of relying on more standard forms and reports, this clinic used Facebook, Twitter, and YouTube to engage with patients and gather their responses. (Fischer & Reuber, 2011) highlight the importance of such an action by describing social media as a “user-friendly” means of “sharing user-generated material.”

Table 4-2: social network group for B2B (LinkedIn platform)

Groups	Subjects/Goals	Founded	Members	Activity and growth (Analytics tool for group, DEC 2014) per week	
				Discussion /w	Comment /w
Entrepreneur's Network	Network for Entrepreneurs. A network for businesses aiming at finding resources, answers or expertise.	April 21, 2008	20,001	269	64
Linked Small Business Innovators	Build relationships and strategic connections with small businesses.	July 5, 2009	28,758	198	15
Consultants Network	Group that connects global strategy, management, marketing, finance, business, IT consultants, and freelancers.	October 31, 2007	374,000	212	187
Small Business and Independent Consultant Network	Network of professionals who complement and strengthen each other to connect with appropriate service providers.	April 9, 2009	15,760	215	17
Executive Suite	Private network for senior-level executives.	September 19, 2007	276,914	42	15
Small Biz Nation	A network for small businesses.	March 22, 2010	20,389	133	12
Innovative Marketing, PR, Sales and social media Innovators Innovation Network	Learn and share best practices, ideas, advice, and solutions.	February 2, 2008	345,771	523	13
On Startups – Community For Entrepreneurs	Marketing, sales, financing, operations, and hiring.	September 19, 2007	469,226	967	16

Table 4-3: Social media groups in industrial ecology and sustainable development

Platforms	Groups	Subjects
LinkedIn	International Society for Industrial Ecology (ISIE)	Industrial ecology
	Industrial symbiosis Dansk Symbiose Center	Industrial symbiosis
	Sustainable development group	Sustainable development
Facebook	Industrial Ecology Students and Graduates	Industrial Ecology
	Industrial Ecology Chalmers 2013	Industrial Ecology
	Green Information Technology	Green IT
Tumblr	Modern industrial ecology	Industrial Urban Ecology
Viadeo	Industrial opportunity (in French: Opportunité industrielle)	Industrial synergy
	Eco-project (in French: Éco-Projet)	Ecology and sustainable development
	Industrial ecology (in French: Écologie industrielle)	Industrial ecology
YouTube	Sustainable Development UN	Sustainable development
Blogs	Interface Cut the Fluff	Sustainability
Twitter	IntlSynergies and NISPnetwork	Industrial ecology

Information sharing can also take more specific forms, such as collaborative work on shared documents or group discussion, which trace the information as it is exchanged over time. For example, groups on LinkedIn (equivalent to "hubs" on Viadeo), such as "International Society for Industrial Ecology" or "industrial symbiosis," allow users to learn from and network with other professionals. These groups provide a valuable way for academics and professionals to monitor and keep up to date with global developments in the field of industrial ecology. They allow members to ask questions, get feedback about relevant events, and send invitations to events. They can serve as a forum for resolving business concerns. They can also help researchers obtain unpublished information. For example, according to eMarketer (2015), 94% of business-to-business (B2B) marketers in North America use LinkedIn to distribute content.

Other examples of platforms that facilitate the sharing of information are video sharing sites like YouTube and Dailymotion. On these platforms, anyone can compile a range of videos on a channel (WebTV) they create. Other users may then interact with each other by posting comments. Although they are not really exploited for business purposes, such channels can play useful roles in promoting concepts of industrial ecology and sharing experiences of industrial synergies.

4.4.3 Building of relationships

Another important aspect of social networks is their inherent ability to build relationships. Social relationships play a crucial role in the formation of industrial synergy networks, a fact widely recognized since the seminal study of (Gertler, 1995) in Kalundborg. The basic principle of social network site utilization is similar across different platforms. They typically allow users to create a profile consisting of their personal information, interests, and a photo. Users are then asked to invite friends or acquaintances to join their network, or to form connections with other users of the platform. Over time, they develop a network of contacts. Although this remains to be proven in practice, social network platforms could thus be valuable to businesses that aim to operate in an environmentally sustainable manner. Social networks provide an effective approach for building a network of contacts and, more specifically, one composed of users who possess shared interests or problems.

Specific social network functions that support the building of relationships with second- and third-level contacts (e.g., LinkedIn), or more specifically with “compatible” contacts, could also be useful for supporting the emergence of industrial symbiosis. For example, the “import contacts” function allows a user to import contacts from their email account and add them to the user’s network on a social network site. The implicit function of contact filtering is similarly useful for building relationships. It is generally based on heuristic rules that quantify the level of compatibility between unrelated users (for example, by calculating the number of shared contacts). In the case of industrial synergies, this compatibility is more complicated to evaluate (e.g., input-output compatibility, location), as it is dependent on private information. However, this information could be shared with a neutral, trusted, and secure third party through a social network platform. The platform itself could also automatically exploit this information to propose connections based on compatibility indicators (e.g., geographical distance, by-product compatibility, volume compatibility), public information (e.g., by-product market price and availability, users’ public Web sites) and private information (e.g., by-product type and availability, contaminants, industrial processes). Along this line, a social network platform with access to a think tank of experts and researchers could also foster relationships between organizations, and promote the sharing of knowledge and information.

4.4.4 Community coordination

In social media and social networks, community coordination can take the form of a content management function, executed by a person whose primary role is to encourage discussions and potentially contribute to knowledge and information sharing. It also serves to help exchanges on a social media site within a specific framework of content and ethics. In the context of industrial symbiosis, this function is similar to that of a facilitator, sometimes called a champion (Sakr, Baas, El-Haggar, & Huisingh, 2011; Meneghetti & Nardin, 2012). Since the notion of champion is used frequently in the project management literature, and because industrial symbioses are not necessarily planned, the term “content and community manager” is preferred in this paper.

In social networks, community managers’ primary function is the development and management of organizations’ presence in the network. These managers keep discussions focused on a particular topic (like in other Social Media), while ensuring the confidentiality of the business information that is exchanged. In the context of industrial ecology, a manager could also take a proactive role to create links between organizations in addition to that rather passive role in the community, therefore contributing to industrial synergies. Such a community manager would be a neutral actor with knowledge and experience in industrial ecology and industrial synergy initiation. He or she would have access to private or confidential data and information to be used for the analysis and discovery of synergy opportunities. Consequently, the function of such a facilitator, together with the use of a social network platform, could be instrumental in enabling the collection and analysis of the data required for the initiation of industrial synergies within a virtual business community.

4.4.5 Limits of current social media

Among the four main roles of Social Media, social networks, and other IS applications dedicated to industrial synergies illustrated in Table 3.4, the sharing of information and knowledge is currently the most common in Green social networking. Other roles such as building relationships are found mainly in social network sites such as Facebook, LinkedIn, and Viadeo.

Unlike generic social media platforms, social networks dedicated to industrial synergy initiation could primarily be interested in functions, such as the storage, retrieval, and analysis of confidential business data and information, as well as more advanced functions, such as data filtering and analysis, and potentially even decision support functions. The main role of these types of social functions is to gather data (e.g., browser, location, IP address, search queries, profile information) through different methods (e.g., third parties, cookies, log data, device tracking technology) in order to use and analyze this data to provide synergy solutions, send detailed information to companies, or send notification to alert users about potential opportunities. However, to implement these advanced functions, the taxonomical classification of resources (e.g., waste material) remains a challenge to address, insofar as they require a common language to produce relevant search results (Grant, Seager, Massard, & Nies, 2010).

Similarly, the community coordination function of current social media and social network platforms has not yet reached a level that is appropriate for promoting the bottom-up emergence of industrial synergies. In practice, coordination is mainly carried out by facilitators who act as a catalyst between potential partners (e.g., NISP). To our knowledge, there is no social media that automatically and transparently carries out such a function. Online classifieds sites (e.g., BRIQ) only propose simple user-directed search mechanisms based on categories and keywords. Other platforms, such as Second Cycle, exploit users' profile information. However, the platform owner is directly responsible for most of the publishing, search processes, and coordination to support the emergence of industrial synergies, which is carried out offline. The online functions of these applications mainly aim to reduce search costs for sellers and buyers of waste. As far as we can observe from their public profile information, these platforms do not yet automatically contribute to the development of relationships between producers and potential users of waste. Therefore, in order to further explore the potential role of social networks to support the initiation of industrial synergies, the next section introduces and discusses specific social media functions, and proposes a list of practices and functions that could support interactivity and the subsequent building of business relationships.

4.5 Functions for Green Social Networking

The general roles of social media and social networks described in the previous section are performed through diverse specific social functions within a computer application or program.

Some of these functions could support several aspects of the initiation of an industrial synergy. Therefore, this section first analyzes the specific functions of various social media platforms and Information Systems applications dedicated to industrial synergies as synthesized in Table 3.4. In particular, we examine how these functions enable the discovery of similar, complementary, and shared interests between different users/parties and professional communities, which has been identified as being useful for initiating industrial synergy and developing knowledge (Grant, Seager, Massard, & Nies, 2010).

4.5.1 Social media functions to support sustainable development

In this section, we explore different social media sources and tools, such as Twitter and Facebook, in order to present common functions and end uses that employ different vocabularies. Because of the ongoing transformation of the social media landscape, this analysis is ongoing and exploratory. Hence, because different social media platforms employ different lexicons (Table 3.5), we first classify social media functions into two categories: primary and secondary. Primary functions are related to initial information exchanges and discussions. Indeed, exchange and discussion are the most basic features of social media, even if different platforms use a different vocabulary to describe these processes. For instance, similar information exchanges might happen through “sharing” on Facebook, “retweeting” on Twitter, or “riffing” on So.cl. Secondary functions of social media, which are sometimes referred to as “accessories,” are used to build upon and complement primary functions, and include functions such as event creation. Secondary functions, such as the process of opening an account, also serve to improve users' experiences before initiating the social processes of sharing and exchanging, and can similarly be used to generate revenues through advertising. In the context of this study, such functions are secondary because they do not directly relate to the basic principles of social networks, which are the existence of contacts and the formation of connections between contacts (Barnes, 1954).

Table 4-4: General roles of existing social media platforms and IS applications dedicated to industrial synergies

	Platform	***Share knowledge***	***Share information***	***Build relationship***					***Coordination***			
				Mode		***Purpose***			***Nature***			
				Self-organized	*Planned*	*Information and knowledge sharing*	*Industrial synergy initiation*	*Industrial synergy promotion*	*Interest compatibility*	*Opportunity compatibility*	*Input-output compatibility*	*Question answer compatibility*
Information System dedicated to industrial synergies	*Prestéo*	*X*	-		*X*		*X*				*X*	
	SYNERGYe	*X*	*X*		*X*	*X*	*X*			*X*	*X*	
	BRIQ	-	*X*		*X*		*X*				*X*	
	Second Cycle	*X*	*X*		*X*	*X*	*X*			*X*	*X*	
Social Media dedicated to sustainable developmen t	Carbonrally	*X*	*X*	*X*		*X*			*X*			
	Zerofootprint	-	*X*		*X*	*X*			*X*			
	MakeMeSustainable	*X*	*X*		*X*	*X*			*X*			
	Celsias	*X*	*X*		*X*	*X*			*X*			
	Change.org	*X*	*X*		*X*	*X*	*X*		*X*			
Generic Social Media	*LinkedIn, Viadéo*	*X*	*X*	*X*		*X*	*X*	*X*	*X*			*X*
	FaceBook	-	*X*	*X*		*X*		*X*	-	-	-	-
	Flickr	*X*	*X*	*X*		*X*			-	-	-	-
	Delicious	*X*	*X*	*X*		*X*			*X*			
	Answers_wiki	*X*	*X*	*X*		*X*						*X*
	Youtube	*X*	*X*	*X*		*X*		*X*	-	-	-	-
	Photobucket	*X*	*X*	*X*		*X*			-	-	-	-
	Ask	*X*	*X*	*X*		*X*						

In order to attract and retain members, a social media platform must support them through primary and secondary functions that are useful to the users' daily operations, allowing them to establish effective communication channels through which they can reach each other to achieve specific purposes. This section proposes a classification of primary and secondary functions, and analyzes them with respect to their potential contributions to the development of industrial synergy.

Primary functions of a social media platform

In this classification framework, there are four types of primary functions: information, exchange, discussion, and contact.

Information function: the strength of a social media platform and its community lies in its ability to present and communicate information on a regular basis, and to generate visits. social media platforms organize information in different forms according to the type of community to which they are catering. For example, the social network Digikaa has developed a “social portfolio” function. Here, users can be connected to a project on which they are working or have previously worked on, and add projects directly to their profile in order to improve their profile and experience. The idea is to aggregate users’ professional experiences through a list of projects.

Beyond the simple transmission of information, the structure through which information is presented, organized, and linked to other information is designed with the user experience in perspective. For instance, a user can tag companies as well as other project participants in a particular project, and then the information is automatically relayed onto these other participants' resumes. Similarly, the Google+ platform includes a function called “Spark,” which provides a stream of information that is constantly updated with topics of interest to its users, including articles and videos that appeal to other users. Users can read, view, and share this information with their contacts.

Exchange/sharing function: as mentioned above, the strength of a social media platform is in its ability not only to present (i.e., make someone aware of something for a purpose), but also to communicate and exchange information (i.e., diffuse and transmit information without specific intention). The exchange function is thus characterized by the communication of content that a person or organization wishes to share with other users. This includes articles, opinions, reflections, white papers, promotions, and professional experiences. Users may also share content that they do not necessarily like or agree with. A noteworthy aspect of the exchange function is that such exchanges of content can affect the reputation of each entity involved in the exchange, contributing to building an individual’s e-reputation.

Discussion function: this function extends the aforementioned information and exchange/sharing functions by allowing users to publicly communicate with other social media members through an instant messaging system. This system facilitates the exchange of text messages or files (images, video, sound, etc.) in real time between multiple users connected to the same network. For example, Facebook Messenger is the instant messaging application used by Facebook members. The discussion function also incorporates users’ reactions to content shared by others. The “comment” or “reply” functions typically constitute a major part of the discussion function. “Google Hangouts” is an instant messaging and video chat platform present within Google+ that allows a circle of users to engage in discussions on videos.

Contact function: this function aims to provide access to a number of people who do not have the opportunity to meet each other offline, either by direct (i.e., message sent) or indirect (i.e., introduced by a third party) contact. This contact function takes many forms depending on the level of the connection’s user profile. For example, the first level consists of those with whom there is already interaction through social networking. The second level gives the same person the opportunity to get in touch with another user that has no connection with him or her directly, but with whom he or she shares common ground via their profile data. Green social networking could offer the possibility for each member to know other people’s public profiles, such as their career, experience, skills, interests, the company they work for, the projects they worked on, relationships, etc. With all this information at their disposal, a person could easily get in touch with another person for purposes of Green social networking.

Secondary functions of a social media platform

Secondary functions support primary functions and typically have a lesser social impact. They are quite numerous, and the list below introduces some of the most significant ones.

Search function: this function aims to provide information search capability in order to offer users relevant information. Green social networking should offer information-retrieval functions based on simple pull (e.g., search form) and push techniques (e.g., based on the user profile, browsing history, and declared topics of interest). Advanced information-pulling technics could include delegating repetitive search tasks to an intelligent software agent that systematically retrieves, filters, and presents information to its user. In a "push" information search function, the user plays a less active role as information is "pushed" and provided as a list of recommendations or suggestions.

Membership function: this function aims to manage the process of a user joining a social network by opening an account or adding circles, contacts, connections, fans, followers, and so forth. This process typically features a registration form to be completed with a user's personal information. The way in which members complete their profiles (i.e., whether they fill them out partially or completely) offers a clue about their level of activity on the social media platform. Useful information derived from the membership function is not really found in the way users create their profiles, but rather in the quality of information in their profiles. Certain users intentionally disclose minimal information in order to remain anonymous and avoid mixing their private life with their public life. Different social media platforms feature various membership and profile systems, depending on the nature of the relationship as emphasized by the network (e.g., friendly or professional), in order to best protect users' identities. In a business context of social networking, this function sometimes incorporates functions such as smart address books, business cards, or fan pages. Such potentially business-friendly elements suggest that the membership function could be used as a gateway to devising a synergetic social tool.

Advertising functions: advertising news, posting job positions possibly related to corporate members of social networks, and e-commerce functions (e.g., buying green research reports from members) could be ways to monetize a Green social network (i.e., generate revenues) and keep it alive, while promoting and engaging with other companies on the social network through social ads.

Link function: Many social media sites offer social networking buttons. This function aims to incorporate such buttons into a site or blog in order to provide an audience with a means to establish word-of-mouth advertising to their friends, who, in turn, can join the audience of the initial user. This function is a way to tell others about a relevant website or piece of information that the user wants others to explore. For instance, Facebook implements this function through its "Like" social button. The +1 button of Google+ aims to show that we like or agree with something. Table 3.5 presents social media vocabulary classified by function:

Table 4-5: Classification of social media vocabulary by functions

Functions	Vocabulary
Membership	Follower, member, contact, contributor, user
Information	News feed, channel, breaking news, real time, timeline, tweetstream, status, update
Publish	Post, pins, bookmarks, tweet, comment, wikify, reddit, Digg
Contact	Connect, get introduced, add as a contact
Event	Notification, alert
Exchange/Sharing	Broadcast, share, webcast, retweet, repin,
Ties	Circle, connections, group space, links, community
Discussion	Chatting, message, discussion, instant messaging, InMails, comment, reply, Facebook Messenger, Hangout
Interaction	Like, unlike, unfollow, follow, rate
Tagging	Mention, poke, tag, hashtag

For example, ResearchGate and Academia.edu are successful examples of applications that have a diversity of social functions dedicated to academics. They are forums that help researchers make their work known to a wider scientific community. These applications showcase researchers who want to improve their online visibility (e.g., resume, publication, visibility in the search engines, number of citations) and a means to query (e.g., collaboration, upload a scientific article). Statistics such as views, followers, quotations, and “RGscore” give an overview of growth, activity, and e-reputation for a researcher. Those platforms are mainly financed through job offers, advertisements (i.e., advertisement function) for conferences and the supply of laboratory products.

Analysis

A social network based on these primary and secondary functions aims to provide a variety of services to promote the development of communities with either general or specific interests. For a community with very specific interests, such as the economic development of an industrial cluster or region through means of by-product reuse, these functions should be designed in order to accommodate the development of industrial synergies and symbiosis (either through self-organized, facilitated, or planned modes). Such functions should also acknowledge and cater to the diversity of users (e.g., industries from different sectors, economic development agencies, municipalities, administrative regions, elected officials) and meet any needs for information confidentiality and trustworthiness. The development of industrial symbiosis undoubtedly requires some level of information sharing. However, in practice, this sharing is only done in a context where implicit trust exists, or is developed over time, between potential partners (e.g., serendipitous creation of industrial synergies), or through a trusted third-party (e.g., facilitated approaches such as NISP and CTTEI). Indeed, information exchange between potential partners requires trust, or at least is a condition that affects how far the exchange takes place (Jensen et al., 2011). Consequently, the promotion of industrial symbiosis through a social media platform requires the design of specific sharing, exchange, and information validity assessment functions that support the exchange of quality information and the building of trust between organizations, in order to encourage the development of a membership base, which, in turn, facilitates industrial synergy creation and resource sharing.

4.5.2 Green social networking framework for industrial synergy

Based on this paper's previous definitions of primary and secondary social media functions, a social network has the following characteristics: it is interactive and Web-based, and exhibits social functions with a user-driven database that constantly grows and changes. Consequently, a Green social network (GSN) should have similar characteristics in order to serve specific environmental objectives. Thus, a GSN is an interactive Web-based platform enhanced by social functions. It is based on an active database and aims to contribute to the initiation of industrial synergies, waste material reuse or recycling, or resource-sharing partnerships, with the greater goal of supporting the development of industrial symbiosis and reducing the collective environmental impact of industrial communities.

In order to investigate how GSN could support this process, we analyze the specific contributions of these functions to the initiation of industrial synergies. To do that, we propose a new systematic framework of analysis inspired by industrial engineering techniques in new product design and continuous improvement. Basically, we divide the development of industrial synergies (whether they are self-organized, facilitated, or planned) into three general phases adapted from the general phases of new product design (Cooper, 2001): (1) *Initiation (ideas generation)*; (2) *Concept validation (feasibility) and detailed design*; and (3) *Implementation, operation and continuous improvement*. These general phases are carried out differently according to the nature of the synergy project. For instance, in the context of a planned or facilitated industrial symbiosis, the individual development of each synergy may somehow intersect. In the context of this study, Phases (2) and (3) are outside the scope of this paper. Therefore, they are not discussed hereafter.

Next, in order to analyze how a GSN could contribute to the initiation of industrial synergy, we further divide Phase 1 into four sub-phases. To do that, we extrapolate the first 3 phases of a data-driven improvement technique from Six Sigma to the initiation of an industrial synergy. This technique is DMAIC (i.e., Define, Measure, Analyze, Improve, Control). The first phase, (1) *Need acknowledgment* (e.g., waste material or industrial by-product to manage, material to acquire, inefficient use of resources), corresponds to the identification and definition of the problem and its goal (i.e., Define). The second phase, (2) *Data collection and repository*, includes all aspects related to the collection of information (i.e., from the initiating organization and potential partners) concerning waste flows and resource utilization (e.g., volume, flow dynamic, contamination). The third phase, (3) *Potential synergies identification and preliminary analysis* concerns the identification of a potential solution as well as a basic preliminary feasibility check of the synergy (i.e., preliminary analysis of the viability of the solution, solutions screening). Then, because a synergy involves at least two partners, we add a fourth phase, (4) *Contact*, which requires the potential partners to be somehow connected in order to specifically discuss the identified synergy.

Table 3.6 describes the sub-phases within each of the two opposite development scenarios. A GSN could contribute to these sub-phases in different ways, and to a different extent. Figure 3.1 proposes a framework that identifies the specific contributions a GSN could make with respect to the initiation phase of an industrial synergy project.

Table 4-6: Industrial symbiosis scenarios

Steps of a scenario	Planned scenario/facilitated (top-down)	Emergence scenario (bottom-up)
Need acknowledgement	The third party (local development agency, research centre, etc.) presents a better way to manage waste flows, and promotes a vision of territory development to the companies.	A company acknowledges its need to manage or acquire another company's waste or by-products. By-products are seen as a potential feedstock for another company's processes.
Data collection and repository	Waste flow information is collected and stored.	Waste flow information is collected and stored.
Potential synergies identification and preliminary analysis	Identification of potential synergies by a third-party mandated to improve the management of the wastes or by-products. Preliminary verification of the general feasibility and interests of both the producer and potential user by the third-party.	Identification of one or many potential synergies by the by-product producer or potential user within a given geographic area, based on criteria such as similarity of by-product. Preliminary verification of the general feasibility by the company using key performance indicators.
Contact	Contact between companies is initiated by the third party.	Contact between the companies is initiated by one of them.

In the case of a self-organized initiation of an industrial synergy, the acknowledgment of a need could be triggered by users (i.e., online members) sharing their experiences (i.e., sharing function) or through the posting of public case studies, which allows users to find information related to their context or opportunities. Classification and semantic representation of this information could be instrumental in enabling search functions. Concerning data collection and repository, in both scenarios data must be collected on site. However, the collection of this data could either remain within the company, in the case of self-organized initiation, or be carried out by a third party. In both cases, the membership function of a GSN could allow partners to safely put this data in their private member profile, which could, in turn, be used for analysis and matching purpose.

Concerning the identification of potential synergies, a GSN platform could use private information contained in the organizations' profiles (i.e., membership function) to automatically find potential matches, and so, at a much larger scale than any third-party facilitators could. By disclosing such information in their profile, a GSN could use different technologies (e.g., by-product flow compatibility, semantic similarity with existing synergies) to analyze the compatibility levels between organizations. The GSN platform could also analyze whether users have common interests through their participation in the social network. Tools based on data-mining or web-mining techniques could also be used to automatically sort and analyze large amounts of data to find these compatibilities. If such compatibilities are found based on profile information, the concerned organizations could then be contacted privately through the GSN platform after this preliminary feasibility check. In other words, without the actual planning that a third-party might conduct, the GSN could play the role of a catalyst or middleman between organizations, even before first contact is made. If feasible synergy opportunities are found, the contact phase (i.e., contact function) could be automatically initiated by the GSN platform by sending a formal multi-party invitation to connect, and a description of the synergy opportunity.

In the case of a planned (or even facilitated) synergy, the use of a GSN platform could be characterized by the proactive role of a third-party user (e.g., trusted consultants, economic development agency). For instance, as discussed previously, need acknowledgment could be supported by the sharing of sensitive information contained in an organization's profile. Such sharing of information should be sought by companies through some formal process in order to guarantee that it is only used with the accord of the companies for a specific purpose.

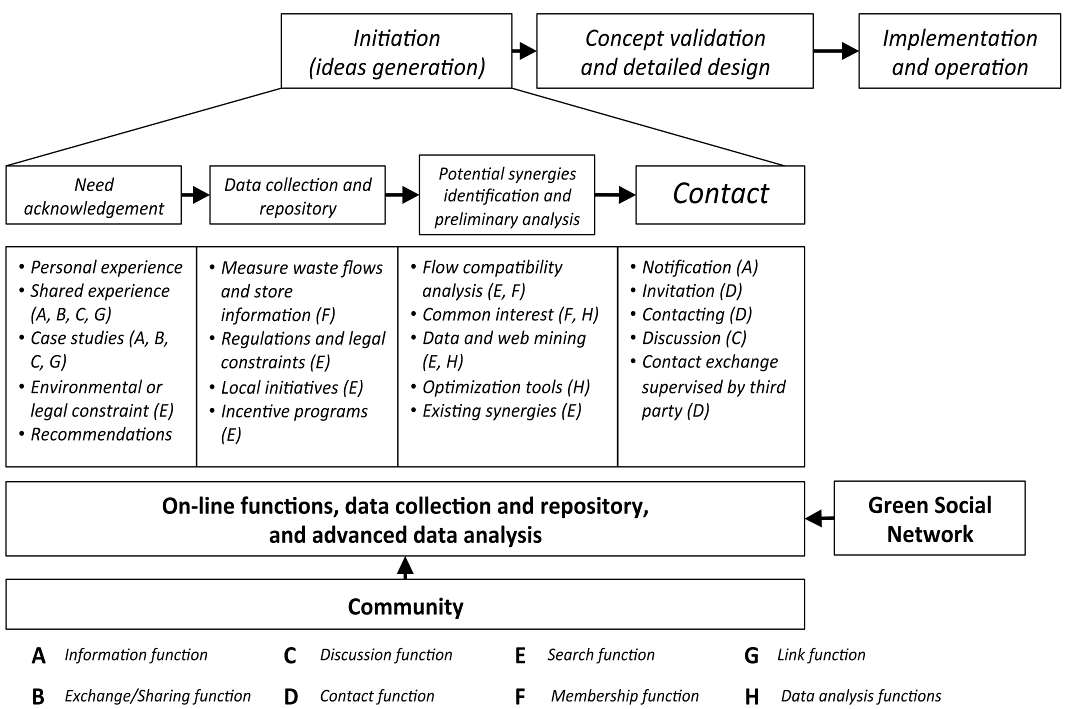


Figure 4-1: Contributions of social media functions to industrial synergy initiation

Next, concerning the last three phases of data collection and repository, identification of a potential synergy, preliminary feasibility analysis, and contact, the process could be similar to that used in the self-organized mode. However, the third-party user could also take a more proactive role, instead of letting the GSN platform automatically carry out compatibility analyzes to identify synergies. In other words, the third-party user could use his or her experience and expertise to directly identify by-product exchange opportunities. Along this line, a GSN platform could also provide the information system capabilities required to manage specific industrial symbiosis projects within limited sub-networks. In other words, a third-party facilitator could register as a facilitator mandated by companies and use the GSN platform for information exchange, sharing, and data analysis within a limited territory. Business models should be developed in order to enable such an open practice.

In any development mode of industrial synergy, a GSN platform could also feature embedded optimization tools, as proposed in (Cimren, Fiksel, Posner, & Sikdar, 2011) and (Maillé & Frayret, 2013), which serve to find optimal or near-optimal synergy configurations within a network of organizations. Such tools could also be used to compute the level of compatibility between organizations, or recommend potential types of industries with high synergistic compatibility amidst a cluster or an eco-park. This kind of advanced matching functions based on material, process, and logistic compatibility still needs to be further developed. Along this line, other functions yet to be developed might also contribute in later phases to the partnership's development. For example, current social media functions and their generic appearance could be re-engineered to allow for a greater degree of privacy, which would encourage organizations to use Green social networks for the purposes of developing industrial symbiosis in a controlled and protected environment.

4.6 Conclusion

With the definition and analysis of the new concept of Green social networking, this paper has highlighted the potential role of online social networking in initiating the development of industrial synergies. By looking at the basic steps towards the initiation of such business partnerships, this paper has analyzed existing social media functions and their potential applications to support industrial synergy initiation. The proposed framework aims to guide the development of next-generation GSN platforms as well as their business models, which have yet to be designed. As such, future work on this subject includes the development of a GSN platform along with the testing and validation of its functions to promote the development of industrial synergies.

An important aspect of social network development that we believe to be instrumental for practitioners concerns the synthesis of feeds, comments, and posts from social network platforms, along with the related production of reports, key performance indicators, and graphic tables highlighting areas of synergistic opportunities. In the medium and long term, the mere design of an information system with certain social functions aimed at green purposes might not be enough to actually promote the ideas and practices of industrial ecologies. With the growing number of members (e.g., communities of interest) and the proliferation of new data sources (e.g., posts, articles, comments, etc.) available on social media, researchers should focus on how Big Data affords new epistemological opportunities in the economic and social sciences and, in turn, creates greater value for businesses by taking advantage of Social Media. In future work, it might also be useful to provide a framework for practitioners that affords a 360-degree view of a company, as information about most businesses is now available in various media on the Web. Finally, in order to promote the use of GSN among businesses, it is also necessary to better understand how businesses currently use social media and social networks, in particular with respect to their advertising and networking functions.

4.7 Aknowledgement

The authors are deeply grateful for the collaboration of the Centre de Transfert Technologique en Écologie Industrielle. We would also like to thank the Fonds Québécois de Recherche en Nature et Technologies (FQRNT) and the Natural Sciences and Engineering Research Council of Canada (NSERC) for their financial support.

CHAPITRE 5 ARTICLE 2 : SOCIAL SEMANTIC WEB FRAMEWORK FOR INDUSTRIAL SYNERGIES INITIATION

Mohamed Raouf Ghali, Jean-Marc Frayret

Journal of Industrial Ecology

Abstract: Industrial symbiosis joins organizations from different economic actors from different sectors together in order to share resources and exchange by-products for mutual environmental, financial and social benefits to participants. Industrial synergies are individual partnerships initiated for the creation of industrial symbiosis. This initiation relies on direct or facilitated information sharing for building collaboration and trust among organizations, which is an essential part for industrial symbiosis. Social semantic web can facilitate the collaborative process of sharing knowledge and information effectively among members of organizations and industrial symbiosis facilitator in order to find, among author things, by-products exchange compatibilities. This paper proposes the SSWISI framework for the initiation of industrial synergies, which is based on social semantic web. This framework adopts the concepts of Linked Open Data (LOD) that enables the sharing and exchanging of information with external systems. This feature distinguishes the proposed framework from the existing approaches to initiation of industrial synergies.

Keywords: Industrial Symbiosis, Industrial Synergies, Social Networks, Semantic Web, Ontologies, Social Semantic Web, Linked Open Data

5.1 Introduction

Industrial ecology (IE) aims to develop and implement strategies to decrease the environmental impacts of by-products and waste associated with industrial systems. It explores various interactions that can occur between industrial systems and the environment. IE adopts a natural paradigm and proposes that an industrial ecosystem can behave like natural ecosystem wherein everything gets recycled (Davis, et al., 2010), (Ghali, et al., 2016) To do so, it needs to create loops in which industrial waste and by-products are reused or recycled by others, and share its resources.

Industrial symbiosis (IS) join organizations from different actors from different sectors together in order to share resources, such as energy, materials and water. Exchanges between organizations can be information and ideas about business practices that help in sustainable innovation and are not limited only to material and energy flow (Grant, et al., 2010), (Li & Shi, 2015), (Cecelja, et al., 2015), (Walls & Paquin, 2015). The exchange of information are also helpful for companies to identify appropriate business partners for sharing resources within a business community. IS improves resource utilization and provides mutual environmental, financial and social benefits to participants (Nooij, 2014), (Raafat, et al., 2013). It creates collaboration between organizations, which is also known as IS-Network. It has been revealed though empirical studies that IS can replicate the behaviors of natural ecosystems where wastes from one organism become resources for another (Grant, et al., 2010), (Li & Shi, 2015). However, contrary to natural ecosystems, the development of IS requires collecting, processing, organizing, and sharing large amount of data and knowledge. Furthermore, potential partners in such collaborative arrangements do not always have sufficient information about each other in order to the initiation the industrial synergy development (Ghali, et al., 2016). Collaborators need to recognize each other, develop relationship over time and reduce the psychological distance between them. IS networks development requires information and knowledge on both technical and social details, and especially about industrial flows for exploring the possible relationships among organizations (Walls & Paquin, 2015).

World Wide Web (WWW) has proven itself to enable collaboration among potential partners in collective actions (Davis, et al., 2010). The web efficiently supports the building of a collective body of knowledge and the creation of feedback loops so that information, once gathered, can be reused for enabling collaboration among organizations. Recently, multiple approaches (Cecelja, et al., 2015), (Ghali, et al., 2016), (Nooij, 2014), based on web technologies have emerged in order to develop industrial symbiosis. However, the existing approaches do not exploit the full potential of current web technologies. Social semantic web (Breslin, et al., 2011), (Passant, et al., 2010) is the integration of leading web technologies: social networks (Musial & Kazienko, 2013) and semantic web (Berners-Lee, et al., 2001), (Ding, et al., 2007), (Horrocks, 2008). It can enable industries engagement, participation, exchange, and interaction, and contribute to the creation of explicit and semantically rich knowledge representations that can prove helpful for the initiation of industrial synergies.

This paper proposes a framework that exploits the potential of social semantic web in order to foster collaboration, and sharing of knowledge and information among members of online industrial communities. This framework, called SSWISI, extends the features of the currently existing approaches (Cecelja, et al., 2015), (Ghali, et al., 2016), (Nooij, 2014) and integrate them into a hybrid approach for industrial symbiosis development. It is a web-based approach that can be openly accessed by anyone only through registration. The distinguishing feature of this framework is information sharing with other external systems through the Linked Open Data (LOD) concept (Bizer, et al., 2009), (Davies & Edwards, 2012), (Heath & Bizer, 2011).

Section 2 describes the background technologies essential to understand the SSWISI framework and its organization. Section 3 explores and analyzes the existing approaches dedicated to industrial symbiosis development. Section 4 introduces the SSWISI framework. Section 5 concludes the paper and presents future research opportunities.

5.2 Concepts and definition

This section outlines the technological concepts our approach is based on: (a) Semantic Web; (b) Semantic Web Languages; (c) Ontologies; (d) Semantic Web Query Language; (e) Linked Oped Data - Dbpedia; (f) FOAF Ontology and (g) Social Semantic Web. These technologies have made possible the development of the SSWISI framework for industrial synergy initiation.

5.2.1 Semantic Web

The Semantic Web (Web3.0) offers a common framework where data can be shared and reused among multiple applications (Berners-Lee, et al., 2001), (Butt & Khan, 2014). It extends the current web through standards defined by the World Wide Web Consortium (W3C) and presents information with well-defined meanings. Its design goal is to empower computers to work or think like humans that can effectively process data on the web. Semantic Web is the web of things rather than the web of documents. It describes the relationship among things and their properties, so that computers can clearly recognize the nature and relationships of things through their properties. Consequently, it helps to retrieve knowledge, rather than data, from the web (Butt & Khan, 2014), (Horrocks, 2008).

5.2.1.1 Semantic Web Language

Semantic Web transforms data into information by including sufficient structure around it. Multiple universal information formats exist that incorporate structure to data, as well as metadata on Semantic Web. These formats are recognized as Semantic Web languages/standards. These standards facilitate data integration and interoperability on the Semantic Web (Ding, et al., 2007). They are based on XML or use XML serialization. Resource Description Framework (RDF) is a language that provides basic syntax to represent information and to share data in the Web. It is recommended by W3C as a standard for semantic web (Anon., 2014). There are three fundamental concepts: (i) resources, (ii) properties, (iii) statements. Resources are 'things' that are illustrated by the RDF expressions. A unique identifier is allotted to each resource that is called Universal Resource Identifier (URI). The relationship between two resources is established through Properties. A resource along with its associated property and value for that property originates a statement. An RDF statement is also called "Triple" that comprises three different parts that are categorized as subject, predicate and object respectively. Subjects and predicates are resources in an RDF statement and an object could be a resource or a literal. A RDF model, comprising a set of RDF triples, represents a directed graph of information for illustrating personal information as well as social networks. Moreover, it facilitates in integrating information over disparate sources of information. Different concepts and their semantic relationships can be effectively represented by an unlimited large graph of information (Butt & Khan, 2014). Resource Description Framework Schema (RDFS) and Web Ontology Language (OWL) have designed to be used by applications for information processing purpose rather than just for information representation (Anon., 2000). These languages describe vocabularies/ontologies in terms of *Class*, *Property*, *Domain*, and *Range*. They assist in carrying out interoperability and reasoning on the Semantic Web (Anon., 2012), (Anon., 2004).

5.2.1.2 Ontologies

The core of the Semantic Web is ontologies (Ding, et al., 2007). Ontologies are defined as an explicit and formal specification of a shared conceptualization (Gruber, 1995). They were initially developed by the Artificial Intelligence (AI) community in order to facilitate knowledge sharing and reuse of existing information effectively. Ontologies represent knowledge domains in terms of concepts and relations between them. They describe real-world terms in a formal language such as RDFS, OWL. They can create an integrated view of multidisciplinary information. They represent a data source at a higher level of abstraction and manifest the semantics of a source. Data in ontologies is self-describing, which makes it readable by machines and can be used in reasoning to categorize and find associations in it (Butt & Khan, 2014), (Farid, et al., 2016).

5.2.1.3 Semantic Web Query Language - SPARQL

RDF is a flexible and extensible way to represent information about WWW resources. The data, stored in RDF format, can be retrieved and manipulated by the semantic web query language (SPARQL). SPARQL (Anon., 2013), (Karim, et al., 2015), (Butt & Khan, 2014) is a graph-matching query language. Each SPARQL query consists of a set of triple patterns that is inherently a graph pattern. Triple patterns are identical to RDF triples apart from each of the subject, predicate and object may be a variable. In processing a SPARQL query, the query graph pattern is matched with a subgraph of RDF data and its variables are replaced with RDF terms from the subgraph. The query result is basically a RDF graph that is identical to the subgraph. A SPARQL query can retrieve data from different sources if their data is stored in RDF format or represented as RDF through middleware (Butt & Khan, 2014), (Karim, et al., 2015).

5.2.1.4 Linked Open Data – Dbpedia

Linked Data is a method where structured data is interlined using RDF on the web and becomes more useful through semantic queries (Auer, et al., 2011), (Bizer, 2009), (Bizer, et al., 2009), (Heath & Bizer, 2011), (Lehmann, et al., 2015). Tim Berners-Lee defined fundamentals that can effectively publish and connect structured data on the web if it follows the linked data principles. These principles guide how to use standardized web technologies to set data-level links between data that belong to diverse sources. Linked data identifies web documents and arbitrary real-world entities in the documents using HTTP URIs. The data-level links, that is RDF triples, connect data from diverse sources into a single global data space. These links between data items of diverse sources facilitate a user to navigate from one data source to other sources using a Semantic Web browser.

The software applications, designed based on Web 2.0, work with a predetermined data sources. However, linked data applications, utilizing data-level links, can find new data sources at runtime. Linked data applications can produce comparatively complete and updated answers because they consult with new data sources appear on the web (Lehmann, et al., 2015). Linked Open Data (LOD) is linked data which is released under an open license and allow the reuse of data free of cost.

The LOD project goal is to makes different open data sources available on the Web and sets RDF links between their data items for building huge datasets (Bizer, 2009). LOD formats are making multiple datasets to be integrated and jointly exploited by SPARQL.

Wikipedia, a social networking site, provides only full-text searching capabilities for accessing its contents, which is very limited access to this useful knowledge base.

Moreover, there are many complex issues in the collaboratively edited data of Wikipedia (e.g., contradictory data, inconsistent taxonomical conventions, errors, and even spam) (Simov & Kiryakov, 2015), (Bizer, et al., 2009), (Heath & Bizer, 2011). The DBpedia project converts Wikipedia content into structured knowledge (i.e. Linked Data). DBpedia, a community project, extracts structured information from Wikipedia and make it available on the web as LOD. Complex queries can be posed against DBpedia datasets for retrieving useful information. Other datasets on the web can be linked with Wikipedia data through DBpedia.

5.2.1.5 Linked Open Data - FOAF

Friend-Of-A-Friend (FOAF) is an ontology that describes people, their activities and their relations to one another and objects (Brickley & Miller, 2010). OWL and/or RDFS have been used to define the FOAF ontology. FOAF allows groups of people to establish social networks among themselves without the need of their own computational resources. User' profiles comprise links to their friends' profiles and produces a homogenous social network (HSN) (Ding, et al., 2007), (Sapkota, et al., 2015), (Golbeck & Rothstein, 2008). Every internet user can use FOAF for free to create his personal profile and to define his or her relationships. Every user has a unique identity in FOAF. These identities empower computers to recognize people who are identical or who maintain identical relationships or have identical interest. Recently, the FOAF format has been adopted by many social networking sites (SNS) in order to exchange user profile information (Musial & Kazienko, 2013). Different FOAF documents can be combined among themselves to generate a unified database of information. FOAF adopts the concept of linked data and links together web of decentralized descriptions.

5.2.2 Social semantic web

The social web links people through the World Wide Web. It is a set of social applications and has launched a novel form of users' interaction with and via the web. The web has been turned from a read only medium to a widely available, collaborative read-write Web (Golbeck & Rothstein, 2008), (Passant, et al., 2010). Huge amounts of user contributions exist within each individual social application. However, those contributions are often available only within the walls of that very application. Thus, it prevents the seamless integration of the contributed data and knowledge. The disadvantage of most of these applications is isolation from the rest of the web (Passant, et al., 2010).

Semantic web presents data with well-defined semantics and thus makes data available for automated discovery and integration across distributed applications (Berners-Lee, et al., 2001). In order to develop collective knowledge systems, the social web requires data interoperability across applications. The semantic web technologies can assist the social web for data interoperability by explicitly defining the structure and meaning of data and knowledge. The integration of social and semantic webs can facilitate the creation of collective knowledge across different social applications (Gruber, 2008), (Breslin, et al., 2011). This integration has resulted in a new paradigm known as Social Semantic Web (SSW). SSW facilitates the creation, management and sharing of information by combining the technologies and approaches from both webs (Breslin, et al., 2011).

SSW creates explicit and semantically rich knowledge representations of the social interactions taking place within each system. It can represent the collective knowledge systems as a large graph. SSW systems can provide as much useful information as much users contribute to the collective knowledge stored in them.

5.3 Online-Existing Approaches to IS

Industrial symbiosis (IS) are industrial networks that cooperatively optimize their use of resource among different industries for economic, environmental and social benefits to local communities. Individual IS links are called industrial synergies. They are often built, but not necessarily, between companies of different sectors that do not have traditional supply chain relationships. Grant *et al*. (Grant, et al., 2010) recognized both explicit and tacit knowledge as pre-requisites for developing and spreading the IS culture and principles into common practice. Explicit knowledge can be easily expressed, or represented and communicated with various tools. However, tacit knowledge is the know-how or experience of individuals and companies' staff. It is difficult to express in written forms. Therefore, developing the IS culture and principles, and eventually developing industrial synergies require collecting, processing, organizing, and sharing large amounts of data and knowledge. Online/Computer-supported systems can play a significant role to foster such collaboration, and enable reuse, organization and expansion of datasets and knowledge within the industrial ecology community of researchers and practitioners (Davis, et al., 2010), (Grant, et al., 2010).

Several computer-supported approaches to develop IS culture and principles have been developed to, among other things, identify industrial synergies in industrial clusters or parks. These systems support various functions for saving, storing, transforming, processing and publishing data from one or several sources, and transmitting this data to one or several destinations. However, as seen further, they are complicated that need a high level of user involvement and systems knowledge to operate. In other words, their main goal is to assist users in searching industrial synergy opportunities. However, their access is usually restricted to peculiar users through an online portal or license (Cecelja, et al., 2015), (Ghali, et al., 2016), (Grant, et al., 2010). Moreover, they are not intended to active participation and communication among users, which is the main means of sharing tacit knowledge. The development of web technologies, particularly Web 2.0 and Web 3.0, has shaped new technologies for sharing both the explicit and tacit knowledge that is required for developing and spreading IS practice. In the next sections, we analyze the features of recent web technologies-based approaches to IS development.

5.3.1 Enipedia

The first tool analyzed here is referred to as Enipedia. It is a semantic wiki which aim is to develop IS practice. The idea behind this approach is that IS can be developed by means of studying existing real words examples of IS case studies. Enipdia is a hybrid technology of wiki and ontology, where wiki enables to collect and share knowledge and information contributions, and where ontology specifies how the concepts in these contributions relate to each other (Nooij, 2014). In this approach, there are two important elements (also referred to as categories) contributing to establishing industrial synergies: *facilities* and *synergy links* that connect facilities. Facility can be by-products, companies, or any by-products provider or user. Facilities have their properties, such as industry type, industry location and composition of a by-product. They are illustrated in a wiki page throughthe synergy link. Therefore, such a repository of information and knowledge could potentially be very useful for finding by-products exchange opportunities. In other words, with Enipedia, a firm with a specific by-product could easily find information related to potential uses of its by-products, as well as the types and sectors of firm that could use it. However, these data sets do not contain any information about potential specific users of by-products nor social connection to share experience. Therefore, another IS-event element was introduced in Enipedia in order to store social interaction information. For example, an IS-event can be match-making workshop organized by a third-party.

This tool was designed and tested with two case studies' data. However, the proposed approach does not cover the complete conceptual scope of IS. It should take advantage of a larger base of potential contributors. Furthermore, the proposed ontology of Enipedia cannot link with external data sources for exchanging information and sharing knowledge because it does not adopt linked data concept.

5.3.2 eSymbiosis

This approach uses ontology to model and formalize the knowledge in the domain of IS (Cecelja, et al., 2015), (Raafat, et al., 2013), (Trokanas, et al., 2014). Their proposed ontology comprises three high level modules: (i) IS matching process ontology, (ii) IS domain ontology and (iii) IS service description ontology. The three modules form the IS meta-ontology. The IS domain ontology is used for descripting material (or energy) processing technologies and input-output requirements. It was designed with four different levels of abstraction for conceptualization, that include a meta-level, an upper-level, a domain level and an instantiation level ontology. The approach was implemented as an automated web service, thus reducing costs and easing its integration to other systems.

In brief, the eSymbiosis approach (Cecelja, et al., 2015) focuses on developing ontology dedicated to modeling and analyzing knowledge. It ignores social network, where users and companies can actively participate, exchange, and interact among themselves for sharing tacit knowledge. Moreover, the proposed ontology of eSymbiosis cannot link with external data sources for exchanging information and sharing knowledge, because, like Enipedia, it does not adopt linked data concept. In other words, the knowledge-base of this system is restricted to data that is fed in it and is not dynamic.

5.3.3 Green Social Networking

Ghali *et al*. (Ghali, et al., 2016) introduced the concept of Green Social Networking (GSN). In this paper, they systematically analyzed social networking in a way that can lead to the development of online social networks that can support the formation of industrial synergies. They also show that online social networks can be used in order to support their members/users to discover solutions to the problems that have already been solved by other members. This type of cooperation on social networks enables experts to propagate their competence and contribute to creating their online reputation. This approach also helps non-contributing members to take benefits of exchanged knowledge by receiving emails or notifications for each new discussion. Moreover, social networks build relationships and develop trust among partners that play a crucial role in the formation of IS.

The GSN approach (Ghali, et al., 2016) adopts social networks and their functionalities for sharing knowledge among companies and other users for initiating industrial synergies. However, social networking sites are knowledge islands and not linked with other knowledge bases. On their own, social networking sites are difficult to integrate with each other because their data is not rich semantically (Mikroyannidis, 2007), (Passant, et al., 2010).

5.3.4 Critical Analysis of Existing Systems

These web-based technologies of IS development (Nooij, 2014), (Cecelja, et al., 2015), (Ghali, et al., 2016) contributes to the industrial synergies initiation phase to a certain level. However, they do not exploit the full potential of current web technologies (i.e., social semantic web) where participation, exchange, and interaction among companies and other users within and across each system can take place. In addition, SSW facilitate in the creation of explicit and semantically rich knowledge that can contribute to the initiation of industrial synergies. Hereafter, we compare these web-based approaches with respect to the social semantic web features as shown in table 4.1.

Table 5-1: Comparative analysis of web-based approaches to IS development

	Rich Knowledge Representation	Creativity & Innovation	Globalization	Active User Participation
Enipedia	**Yes**	**Yes**	**No**	**Yes**
eSymbiosis	**Yes**	**Yes**	**No**	**No**
GSN	**No**	**No**	**No**	**Yes**

On the one hand, table 4.1 shows that Enipedia and eSymbiosis use rich knowledge representation because they deploy ontology for storing information, which, in turn, foster creativity and innovation by letting users explore the logical associations among the concepts of ontologies. On the other hand, active user participation takes place in Enipedia and GSN because both approaches use social networks to support user interaction and collaboration in order to initiate industrial synergies. Moreover, industrial symbiosis involves organizations from different economic actors, from different sectors in order to share resources and exchange by-products. It is also a dynamic domain of knowledge in which new industrial synergies enabling technologies are constantly developed. Therefore, a single master ontology or repository (i.e., a site of social network) cannot possibly describe all information. Indeed, different sources of information are being developed in this domain (Davis et al., 2010). Consequently, the notion of linked open data, which supports information exchange among autonomous information sources, can be instrumental to integrate this information into a coherent and organized data web. However, these approaches do not adopt these concepts and are restricted to data that is fed to them and do not exchange information with external resources for globalization.

5.4 Proposed Framework - SSWISI

Industrial Networks emerged from networks of personal contacts (i.e., people who work for different companies) initiated by necessity (e.g., supplier selection), to take advantage of an opportunity (e.g., partnership), or by pre-existing personal relationship (e.g., personal acquaintance). Industrial Networks are forged by people who eventually exchange information and work together to achieve their goals. Sharing experience (both at the individual and corporate levels) about by-products and industrial waste, or personal knowledge in industrial ecology, can lead to the discovery of by-product exchange compatibilities and other synergistic opportunities (Ghali, et al., 2016), which can in turn lead to the creation of industrial synergies. Therefore, the initiation of industrial synergies can benefit from the modelling of both explicit and tacit knowledge.

Web technologies have been recognized as a potential solution for sharing both explicit and tacit knowledge (Davis, et al., 2010), (Ghali, et al., 2016), (Nooij, 2014). In this work, we propose a framework based on Social Semantic Web (SSW) (Breslin, et al., 2011), (Mikroyannidis, 2007), (Golbeck & Rothstein, 2008) to support the early phase of industrial synergies initiation. In this framework, referred to as Social Semantic Web for Industrial Synergies Initiation (SSWISI), we adopt and integrate some features of Enipedia, eSymboisis, and Green Social Networking. SSWISI is an interactive web-based platform enhanced by social functions. It is based on ontologies that contribute to the sharing of knowledge and experience.

The main components of the framework are: semantic web (Berners-Lee, et al., 2001), (Horrocks, 2008) and social networks (Musial & Kazienko, 2013). Ontology, the semantic web core, plays a backend role of structuring knowledge and information, while social networks play a frontend role of enabling both direct interactions between users, and the sharing of their individual experience.

Social networks facilitate (i) learning from each other; (ii) information sharing; (iii) relationship building; and (4) community coordination (Ghali, et al., 2016). These features can contribute to stimulating social connections, and, ultimately lead to the identification of material flow compatibilities (Davis, et al., 2010), (Ghali, et al., 2016). On the other hand, semantic web (i.e., through the adoption of ontologies) provides the means to organize, connect and retrieve data, information and knowledge to efficiently enable the extraction of relevant information and knowledge about by-products exchanges.

5.4.1 SSWISI Ontology – OntoEco

An ontology can be used to model the tacit knowledge of companies' staff, or any other research or technology transfer center, related to waste and by-product streams (i.e., material, energy, water), their treatment, their processing, their handling, as well as the difficulties and solutions related to the development of their exchange with other companies. Similarly, an ontology can also be used to model the explicit knowledge of industrial symbiosis or synergy members, or any other potential partners, in the form of relevant information about their processing capabilities, supply needs or inventory constraints, that can be used to identify potentially interested by-product exchange partners (Cecelja, et al., 2015), (Trokanas, et al., 2014). In order to address this, this framework has been built on the conceptual model of the eSymbiosis's ontology and extended it.

OntoEco is an IS related ontology that is structured into four layers of abstraction as the eSymbiosis ontology. However, the concepts and properties in OntoEco have not been imported from eSymbiosis. Because by-products exchanges are often a form of innovation developed all over the world, and because industrial ecology is not yet a mature domain of knowledge, knowledge is often implicit and distributed across companies' staffs and experts. Therefore, in order to accelerate the adoption of the principles of industrial ecology and foster the development of industrial symbiosis, we need to adopt a technology to access this ill-structured and distributed knowledge. In other words, the early phase of industrial synergies initiation needs to explore new data sources and updated knowledge about by-products properties, their processing requirements, classification and composition.

In order to do that, ontologies must be linked to one another in order to automate extended search for information across multiple sources. Using interlinked ontologies, a user can navigate from a data item within one data source to related data items within other sources. In the SSWISI framework, we exploit this linked data concept (Bizer, et al., 2009), (Davies & Edwards, 2012), (Heath & Bizer, 2011), (Simov & Kiryakov, 2015). In other words, any linked data applications based on the SSWISI framework can discover new data sources and updated knowledge at runtime by following data-level links (i.e. URIs aligned with classes/properties), and can thus deliver more complete answers as new data sources appear on the Web.

Ontology models are structured with respect to concepts, properties and associations (Horrocks, 2008), (Farid, et al., 2016). In this framework, the concepts, properties and associations of OntoEco are imported from external ontologies thanks to Linked Open Data (LOD) (e.g., DBpedia (Anon., n.d.); FOAF (Brickley & Miller, 2010); and schema.org (Anon., n.d.)). The external ontologies are not limited to these three ones. This import features in OntoEco enable OntoEco to be linked with external resources for discovering updated knowledge and new data sources in clouds of open data on the web. Moreover, it distinguishes between OntoEco and both eSymbiosis and Enipedia ontologies, which are close.

The core structure of OntoEco is illustrated in Figure 5-1. The ontological structure of OntoEco is divided into three segments located in three distinct ontological files: OntoEco-Schema, OntoEco-Data, OntoEco-rq. First, OntoEco-Schema supports the conceptual structure of the ontology. Next, OntoEco-Data preserves data (i.e., instances of OntoEco); and the third ontology contains SPARQL queries. In the remaining subsection, we describe these segments in details.

.

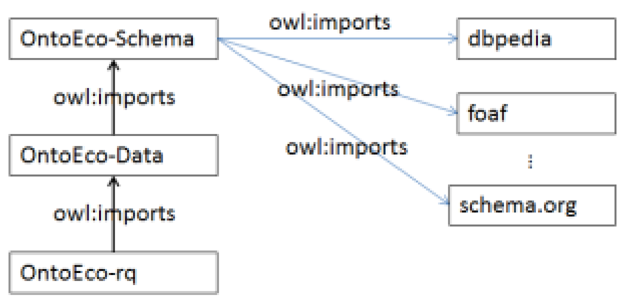


Figure 5-2: OntoEco Core Structure

5.4.1.1 OntoEco-Schema

OntoEco-Schema is the domain ontology that models both tacit and explicit knowledge collected by IS practitioners and experts. The ontology is structured into four layers of abstraction: meta, top, domain and instantiation levels as shown in Figure 5 2. The meta-level describes general concepts independent of the domain and facilitates sharing and reusing.

The concept *Thing* is the base class of all ontology classes. The concept *Agent* is a subclass of *Thing*; similarly, *Organization* is a subclass of *Agent*. They are DBpedia classes. *Agent* represents things that perform some activities and *Organization* represents social institutions such as companies, societies. These classes have been mapped with FOAF and schema.org with the sameAs property. The top-level of OntoEco describes its basic structure and contains the following abstract concepts.

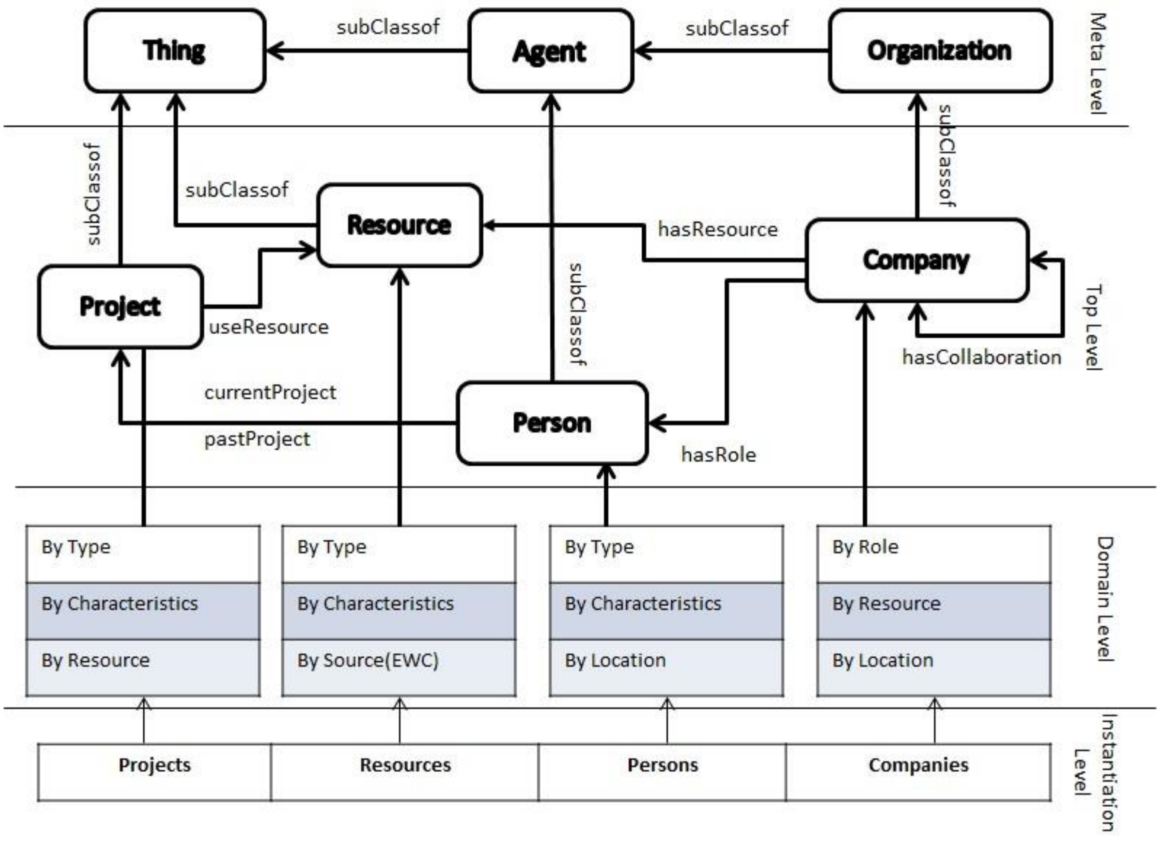


Figure 5-3: Design of OntoEco Ontology

1. ***Company***. It is a subclass of Organization in Dbpedia and represents a kind of *Agent* corresponding to companies or industries. The *Company* class and its properties present industries involved in the initiation of synergies. It has been further classified through properties on the basis of By-Role (e.g., Owner, Key Person), By-Product (e.g., Fuel, Energy, water), By-Location (e.g. City, Country).

2. ***Person***. It is a subclass of *Agent* class and represents people since all people are considered 'agents' in FOAF. This class is mapped to *Person* class of DBpedia and schema.org through sameAs property. Every user of SSWISI framework is an instance of the *Person* class. This *Person* is associated with hasRole property with *Company*. It has

been further classified By-Type (e.g., ceo, manager), By-Characteristics (e.g., Education, Experience) and By-Location (e.g., City, Country).

3. ***Project***. It is also a subclass of *Thing* that represents a collective endeavor of some kind in FOAF. It represents a particular case study of an industrial synergy or a new synergy that a user would like to initiate. A *Project* is categorized based on By-Type (e.g., thermochemical, mechanical, biochemical), By-Characteristics (e.g. Volume, Funds, Impact) and By-Resource (i.e. a broad category of Resource e.g., Energy, Water, Chemical).

4. ***Resource***. It is a subclass of *Thing* and is mapped to *Product* class of schema.org through the sameAs property. It represents any by-product or service. It refers to material, waste, energy that a user may offer or require. It expresses knowledge accumulated from various sources (i.e., general knowledge on process industry, existing classification of resources and experiential knowledge of resources from past cases). In OntoEco, resources are classified on the basis of By-Type (e.g. water, energy, material), By-Characteristics (i.e. key attributes e.g., hazardousness, processing, phase (solid, liquid or gas) and By- Source (i.e. classification by European Waste Catalogue (EWC, EWC STAT).

The top level of ontology defines its top-level RDF object-properties, which provide relationships between the concepts and RDF data-properties characterizing the concepts. The RDF object and data properties and their domain and ranges are listed in table 4.2. The property list is not exhaustive but denotes all significant properties.

Table 5-2: Significant RDF Properties of OntoEco

Property	***Domain***	***Range***	***Comment***
Surname	Person	rdfs:Literal	Person surname
Lastname	Person	rdfs:Literal	Person last name
currentProject	Person	Project	Current Project of a Person
pastProject	Person	Project	Past Project of a Person
hasCollaboration	Organization	Organization	Collaboration of Organization to another one
hasRole	Organization	Person	Person role in Organization
hasResource	Organization	Resource	Resource of Organization
projectObjective	Project	xsd:string	Defined objective of a project
projectStartDate	Project	xsd:date	The start date of the project
projectEndDate	Project	xsd:date	The end date of the project
Category	Resource	rdfs:Literal/Thing	A category for the item
Description	Resource	xsd:string	A description of the item
isConsumableFor	Resource	Resource	A pointer to another resource

The domain level ontology further appoints concepts from the top-level by embedding their classifications and knowledge on IS obtained from IS experts and practitioners. The domain ontology can contain several thousand concepts, as well as the subsumption of the top levels of concepts, which can be imported from external ontologies. Table 4.3 represents the examples of domain level concepts.

Table 5-3: Examples of Domain Level Concepts

<table>
<tr><th>Top Level Concept</th><th colspan="4">Domain Level Concepts</th></tr>
<tr><td rowspan="21">Company</td><td rowspan="6">By Industry</td><td rowspan="3">Textile Company</td><td>Clothing Company</td><td>…</td></tr>
<tr><td>Carpeting Company</td><td>…</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td rowspan="3">Food Company</td><td>Beverage Company</td><td>…</td></tr>
<tr><td>Sugar Company</td><td>…</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td rowspan="7">By Resource</td><td rowspan="3">Gypsum Company</td><td>Impression Plaster Company</td><td>…</td></tr>
<tr><td>Dental Plaster Company</td><td>…</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td rowspan="4">Gas Company</td><td>Natural Gas Company</td><td>…</td></tr>
<tr><td>Industrial Gas Company</td><td>…</td></tr>
<tr><td>Bio Gas Company</td><td>…</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td rowspan="7">By Location</td><td rowspan="3">United Kingdom Company</td><td>Birmingham Company</td><td>…</td></tr>
<tr><td>Hull Company</td><td>…</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td rowspan="2">Canada Company</td><td>Tumbler Ridge Company</td><td>…</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>Chile Company</td><td>Atacama Desert Company</td><td>…</td></tr>
<tr><td>…</td><td>…</td><td>…</td></tr>
<tr><td>…</td><td>…</td><td>…</td><td>…</td></tr>
</table>

5.4.1.2 OntoEco-Data

The instantiation level of the ontology contains all the instances of ontology classes, including registered users, companies and their properties, which are used to characterize all the concepts. OntoEco-data is used to store instantiation level data (as illustrated in figure 5.3 in a graphical form). In this illustration example, four companies are included in the database of facts:

Novo_Nordisk, Asneas, Statoil and Gyroc_Saint_Godain. Next, industrial synergies between them are revealed through the resource (i.e., by-product) they share. More specifically, Asneas has the following resources: Steam, Gypsum, Cooling_Water and Waste_Water. It is illustrated as instances of the "hasResource" property.

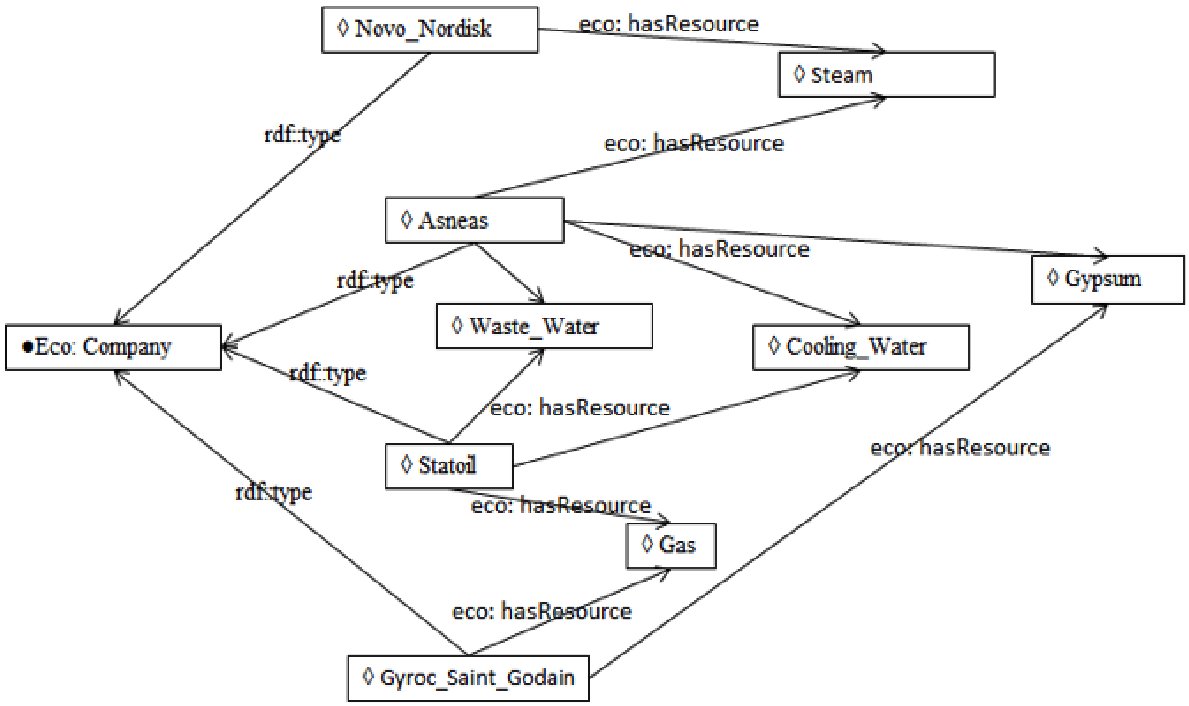


Figure 5-4: Graphical Representation of OntoEco_data

The same data can be represented using Turtle notation as shown in Figure 5.4

```
:Statoil  a  eco:Company ;
       rdfs:label  "Statoil"^^xsd:string ;
       eco:hasResourse  :Gas , :Cooling_Water , :Waste-Water .

:Novo_Nordisk  a  eco:Company ;
       rdfs:label  "Novo Nordisk"^^xsd:string ;
       eco:hasResourse  :Steam .

:Gyproc_Saint_Gobain  a  eco:Company ;
       rdfs:label  "Gyproc Saint Gobain"^^xsd:string ;
       eco:hasResourse :Gypsum , :Gas .

:Asneas  a  eco:Company ;
       rdfs:label  "Asneas"^^xsd:string ;
       eco:hasResourse :Waste-Water ,:Gypsum , :Cooling_Water ,:Steam
```

Figure 5-5: Turtle Representation of OntoEco_data

5.4.1.3 OntoEco-RQ

The third segment of the OntoEco's structure contains SPARQL queries whose aim is to explore OntoEco-schema and its OntoEco-data along with Linked Open Data (LODs) for potential industrial synergies. A SPARQL queries structure of OntoEco-RQ, shown in figure 5.5, represents use-cases which aim is to identify the potential industrial synergies between any two companies. They are developed based on the assumption that if a substitution industrial synergy (e.g., sharing of a by-product) exists between two companies with specific profiles (e.g., a power plant and a petroleum refinery), any pair of companies with similar specific profiles could potentially have a by-product compatibility.

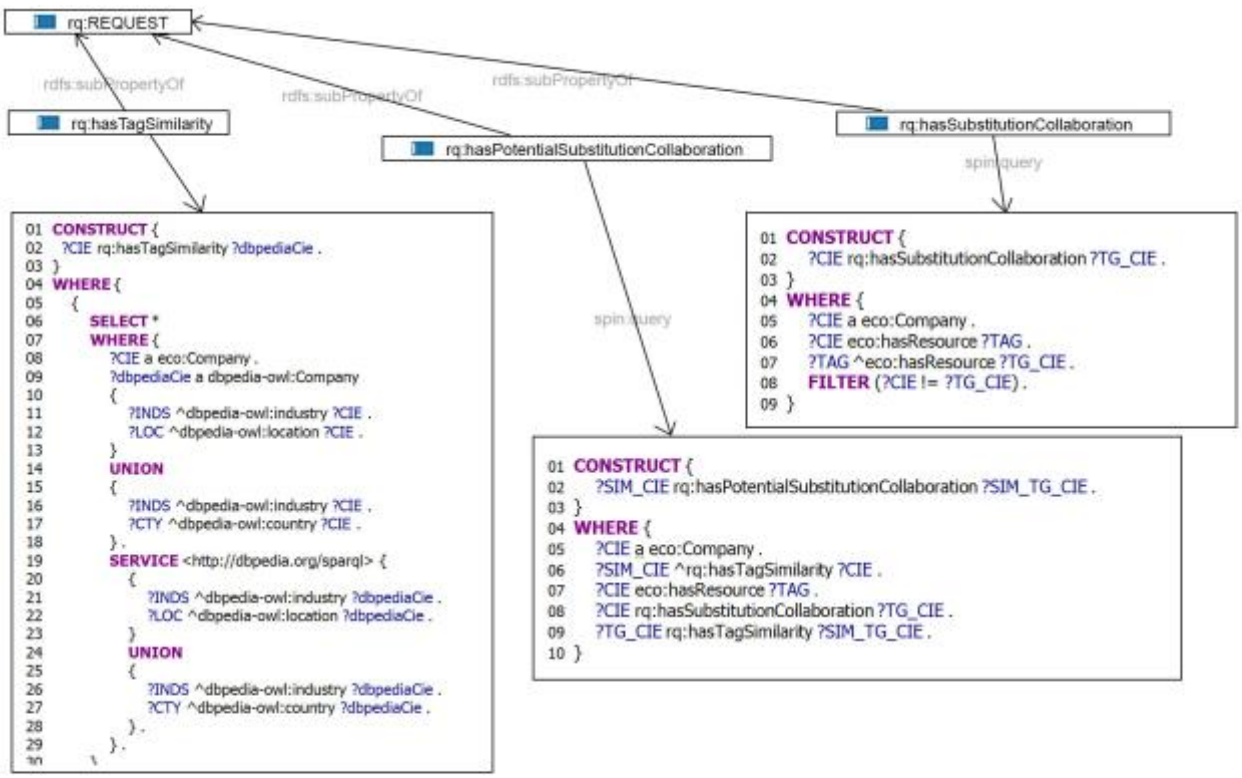


Figure 5-6: Sample SPARQL queries structure of the OntoEco-RQ

First, the query construct rq:hasSubstitutionCollaboration (detailed in figure 5.6) represents a use-case which aims to filter data from OntoEco_data in order to identify existing synergies (i.e., sharing of a resource: *?TAG*) between two companies (i.e., *?CIE and ?TG_CIE)*. In this query construct, the notion of similarity is limited to the sharing of a specific resource. However, other filters can be developed in order to identify more specific and detailed similarities, such as by-product exchanged quantity, type of logistic involved, or by-product sorting or treatment processes involved.

```
CONSTRUCT {
    ?CIE rq:hasSubstitutionCollaboration ?TG_CIE .
}
WHERE {
    ?CIE a eco:Company .
    ?CIE eco:hasResource ?TAG .
    ?TAG ^eco:hasResource ?TG_CIE .
    FILTER (?CIE != ?TG_CIE) .
}
```

Figure 5-7: Query construct rq:hasSubstitutionCollaboration

In order to validate the feasibility of this query construct, we implemented and tested it on a sample dataset (see figure 5.7) where two companies (c.-à-d., *CIE* and *TG_CIE)* are linked with a resource (*TAG*). The result of the query in the form of RDF triples is shown in figure 5.8 that represents a company (Subject) has substitution collaboration with another company (Object).

[CIE]	TAG	TG_CIE
OntoEco-Data:Asneas	OntoEco-Data:Waste-Water	OntoEco-Data:Statoil
OntoEco-Data:Asneas	OntoEco-Data:Gypsum	OntoEco-Data:Gyproc_Saint_Gobain
OntoEco-Data:Asneas	OntoEco-Data:Cooling_Water	OntoEco-Data:Statoil
OntoEco-Data:Asneas	OntoEco-Data:Steam	OntoEco-Data:Novo_Nordisk
OntoEco-Data:Gyproc_Saint_Gobain	OntoEco-Data:Gypsum	OntoEco-Data:Asneas
OntoEco-Data:Gyproc_Saint_Gobain	OntoEco-Data:Gas	OntoEco-Data:Statoil
OntoEco-Data:Novo_Nordisk	OntoEco-Data:Steam	OntoEco-Data:Asneas
OntoEco-Data:Statoil	OntoEco-Data:Gas	OntoEco-Data:Gyproc_Saint_Gobain
OntoEco-Data:Statoil	OntoEco-Data:Cooling_Water	OntoEco-Data:Asneas
OntoEco-Data:Statoil	OntoEco-Data:Waste-Water	OntoEco-Data:Asneas

Figure 5-8: Data sample data for Query :hasSubstitutionCollaboration

[Subject]	Predicate	Object
OntoEco-Data:Asneas	rq:hasSubstitutionCollaboration	OntoEco-Data:Novo_Nordisk
OntoEco-Data:Asneas	rq:hasSubstitutionCollaboration	OntoEco-Data:Gyproc_Saint_Gobain
OntoEco-Data:Asneas	rq:hasSubstitutionCollaboration	OntoEco-Data:Statoil
OntoEco-Data:Gyproc_Saint_Gobain	rq:hasSubstitutionCollaboration	OntoEco-Data:Statoil
OntoEco-Data:Gyproc_Saint_Gobain	rq:hasSubstitutionCollaboration	OntoEco-Data:Asneas
OntoEco-Data:Novo_Nordisk	rq:hasSubstitutionCollaboration	OntoEco-Data:Asneas
OntoEco-Data:Statoil	rq:hasSubstitutionCollaboration	OntoEco-Data:Asneas
OntoEco-Data:Statoil	rq:hasSubstitutionCollaboration	OntoEco-Data:Gyproc_Saint_Gobain

Figure 5-9: Result of Query :hasSubstitutionCollaboration

Next, query construct rq:hasTagSimilarity (detailed in figure 5.9) aims to identify a *Company* (*?CIE*) from the given local ontology (i.e., Ont_Eco), which is deemed similar (i.e., the *Company* has the same instance of specific *Resource*, such as cooling water) to a *Company* in an external knowledgebase i.e., DBpedia (?dbpediaCie) applying search criteria (*?INDS* and *?LOC*) or (*?INDS* and *?CTY*).

```
CONSTRUCT {
  ?CIE rq:hasTagSimilarity ?dbpediaCie .
}
WHERE {
    {
        SELECT *
        WHERE {
          ?CIE a eco:Company .
          ?dbpediaCie a dbpedia-owl:Company
          {
             ?INDS ^dbpedia-owl:industry ?CIE .
             ?LOC ^dbpedia-owl:location ?CIE .
          }
          UNION
          {
             ?INDS ^dbpedia-owl:industry ?CIE .
             ?CTY ^dbpedia-owl:country ?CIE .
          } .
          SERVICE <http://dbpedia.org/sparql> {
             {
                ?INDS ^dbpedia-owl:industry ?dbpediaCie .
                ?LOC ^dbpedia-owl:location ?dbpediaCie .
             }
             UNION
             {
                ?INDS ^dbpedia-owl:industry ?dbpediaCie .
                ?CTY ^dbpedia-owl:country ?dbpediaCie .
             } .
          } .
        }
    } .
}
```

Figure 5-10: Query construct rq:hasTagSimilarity

Finally, the third query construct rq: hasPotentialSubstitutionCollaboration presented in figure 5.10 aims to identify two potential companies (i.e., ?SIM_CIE and ?SIM_TG_CIE) in an external knowledgebase, e.g., DBpedia that can establish an industrial synergy collaboration (i.e., connected through property hasResource) based on their similarities (i.e., using the predicate hasTagSimilarity) with companies (i.e., ?CIE and ?TAG_CIE) that have existing known synergy among themselves in the given local ontology. Both the second and third query constructs have also been executed on the sample dataset for validation and they produced the desired results.

```
CONSTRUCT {
    ?SIM_CIE rq:hasPotentialSubstitutionCollaboration ?SIM_TG_CIE .
}
WHERE {
    ?CIE a eco:Company .
    ?SIM_CIE ^rq:hasTagSimilarity ?CIE .
    ?CIE eco:hasCollaborationTag ?TAG .
    ?CIE rq:hasSubstitutionCollaboration ?TG_CIE .
    ?TG_CIE rq:hasTagSimilarity ?SIM_TG_CIE .
}
```

Figure 5-11: Query construct rq:hasPotentialSubstitutionCollaboration

Used together, these constructs can find pairs of companies which are similar to existing pair of companies known to have an industrial synergy. The notion of similarity used here can be adjusted to match any particular needs. Furthermore, other SPARQL query structures using other concepts of OntoEco-schema can be designed in a similar manner, for instance, to identify potential mutualisation synergies between more than just two companies.

5.4.2 SSWISI - Social Network

Social networks are employed for sharing information in initiating industrial synergies in SSWISI framework. Functions are required in social networks for information sharing and assessing its validity. The functions support the exchange of quality information and building of trust between organizations [Chapter 3]. Moreover, the functions of social networking enable the discovery of similar, complementary and shared interests between different users/groups and professional communities. They are useful for initiating industrial synergy and developing knowledge. Ghali et. al. [Chapter 3]. classified these functions into two categories: primary and secondary. Primary functions support initial information exchange and discussion, while secondary functions complement primary function. For example, “Sharing” on Facebook and “Retweeting” on Twitter are primary functions and event creation and opening an account are secondary functions. Secondary functions are not directly related to the basic principles of social networking which are the existence of contacts and the formation of connections between contacts. The data of the functions are preserved in the SSWISI ontology: OntoEco for record and searching. We summarize the desired functions of social networking, as described with details in [Chapter 3], and mapped them to relevant classes and/or properties of OntoEco in Table 4.4. These functions are manipulated in the initiation of industrial synergies. The SSWISI synergies initiation process has been adopted from Ghali et. al. [Chapter 3] and customized accordingly. There can be four steps in an initiation process.

1. **Need acknowledgement**. Synergies initiation requires declaration of production of waste material or industrial by-products and their consumption. A need is declared by a member of (i.e. Person class) of an Organization by the posting details of a Product in both cases i.e., either consumption or production. The details of the Product help in finding information related to their context and opportunities.

2. **Data collection and repository**. Waste flow information (i.e. both Product and Project classes) is the essence of industrial synergies. Data of Product and Project classes must be collected in case of both production and consumption as instances in OntoEco-Data file and linked with instances of Person and Organization classes. The data is could be used for analysis and matching process.

Table 5-4: Summary of desired social networking functions

Cat	Function	Purpose	Class/Properties
Primary	Information	Aggregate users' professional experiences, create and maintain profile	Manipulate *Person* class and its properties, e.g. education, experience, achievement, activity, project, employer
	Exchange/ Sharing	Communicate information content that is to be shared	Manipulate *Project* and *Product* classes and their properties, e.g. *projectEndDate, ProjectStartDate, projectObjective, releaseDate, purchaseDate, review, weight*
	Discussion	Communicate publically with other social media members in real time	Manipulate mainly *Person* & *Document* classes and their property: *weblog*
	Contact	Get in touch with other people	Manipulate classes e.g., *OnlineAccount, PersonalProfileDocument* and their properties e.g., *accountName, account, familyName*
Secondary	Search	Retrieve relevant information	Manipulate sparql queris of OntoEco-rq.
	Membership	Manage users' registration process	Manipulate *Person* class and its properties e.g. *surname, lastname, birthDate, email*
	Link	Provide a mean to establish	Manipulate *Person* class and its properties e.g. *follows, knows, memberof*

3. **Potential synergies identification and preliminary analysis**. SSWISI platform use instance data of classes stored in OntoEco-Data for finding potential matches. SSWISI use semantic similarity through SPARQL queries to analyze the compatibility levels

between persons, organizations, projects and products. Two types of queries are manipulated in SSWISI framework, batch and ad-hoc. Batch queries are utilized form commonly used search functions of social networks and ad-hoc queries are used for complex analysis. Moreover, data mining and web mining techniques could also help in finding these compatibilities.

4. **Contact**. If feasible opportunities are found, there can be various ways to connect the concerned person and/or organization. The detailed profiles of persons and organizations are available in SSWISI framework. SSWISI functions can automatically initiate the contact process as a middleman between organizations. A third party facilitator can register in SSWISI and participate in information exchange process. He/she can play more proactive role in carryout compatibility analysis to identify synergies using his or her experience and expertise. SSWISI platform can be augmented by including further optimization features which serve to find optimal or near optimal synergy initiations among networked organizations.

5.5 Conclusion

With the development of web technologies, affordable approaches have been enabled to support the early stage of industrial synergies initiation. This paper has proposed an approach for initiating industrial synergies that extends existing approaches. These approaches have analyzed in details the essence of web technologies and their role to initiating industrial synergies. The proposed approach is a hybrid that integrates these approaches with social semantic web. It is a web-based framework approach that is designed to be openly accessed by anyone only through registration. The social networking feature of the framework assists in relationship building and community coordination for sharing of information. Semantic web technology in the framework provides sufficient data structure to transform it into usable information, which is required for data sharing and reuse across applications, enterprises and communities. It also enables advanced search functions that can be used in order to identify potential industrial synergy compatibility. Ontology-based queries constructs were developed, programmed and tested in order to demonstrate the feasibility of such advanced search functions. Another distinguishing feature of the proposed framework concerns the sharing of information with other external systems through import and export of information through Linked Open Data (LOD) concept. The proposed framework leads the road to the development of SSWISI platform for the early phase of the initiation of industrial synergies.

CHAPITRE 6 ARTICLE 3 : AGENT-BASED MODEL OF SELF-ORGANIZED INDUSTRIAL SYMBIOSIS

Mohamed Raouf Ghali, Jean-Marc Frayret, Chahid Ahabchane

Journal of Cleaner Production

Abstract: Industrial synergies are forms of collaborative partnerships between companies resulting in the sharing of resources or the exchange of material or energy by-products. They generally have both economic and environmental benefits. The creation of such innovative partnerships within a territory leads to the development of an industrial symbiosis (IS), which is a dynamic networks of interconnected industrial actors. IS can develop in different manners, with different levels of planning and serendipity, in which the diffusion of trust and knowledge are generally thought to play a key role. This paper proposes and evaluates a simple agent-based model of self-organized IS development capable of simulating the impacts of social factors (i.e., social structure, trust, and knowledge diffusion) on the creation of industrial synergies, and eventually on the emergence of IS. This model was tested using NetLogo. Its consistency with the original design objectives was validated with a sensitivity analysis that considered several factors. Next, experiments were designed and carried out in order to study the influence of the social structure (i.e., types of social network) and dynamics (i.e., creation of new social contacts between plants). Results revealed that both factors have an influence on synergy creation, as IS is a function of both social dynamics and structure. However, more analysis is required to better understand the limits of such a model, as well as to validate the model's assumptions.

Keywords: Industrial symbiosis dynamics; agent-based modeling; simulation; social embeddedness

6.1 Introduction

Industrial synergies are collaborative partnerships between companies resulting in the sharing of resources or the exchange of material or energy by-products. Their development leads to cleaner production processes and more efficient use of resources, which, in turn, contribute to making cleaner industrial societies. They typically include by-product synergies (i.e., re-use of by-products), shared infrastructures, and a joint provision of common resources or services (i.e., collaborative provision of non-core business services or resources). They generally have both economic and environmental benefits. The creation of synergies within a territory leads to the development of industrial symbiosis (IS). In this paper, we adopt the framework proposed by Boons *et al*. (2016), who define "*IS as a process of connecting flows among industrial actors through (1) use of secondary material, water, and energy resources and/or (2) utility and service sharing, such as collective use of infrastructure or environmentally related services across a network*." IS are dynamic networks of interconnected industrial actors. They can be initiated in different manners. Boons *et al*. (2016) proposes seven IS dynamics inferred from empirical observations. This paper proposes a simple model capable of simulating self-organized IS (Chertow, 2007).

Modeling and simulating a Complex Adaptive System requires the identification of factors that drive the behavior of its components in terms of decision making and interaction with their environment and each other. In the context of self-organized IS, geographic proximity, social embeddedness, and trust are identified as positive factors and enablers of industrial symbiosis development (Velenturf and Jensen, 2016; Chertow and Ehrenfeld, 2012; Ashton and Bain, 2012; Gibbs, 2003; and Hewes and Lyons, 2008).

Along these lines, the objective of this paper is to propose and evaluate a simple agent-based model of self-organized IS development capable of simulating the impacts of social factors (i.e., social structure and dynamics, trust, knowledge sharing) on their emergence.

This paper is organized as follows. Section 2 presents a literature review of self-organized IS and agent-based models of IS. Section 3 presents the model, while Section 4 presents and discuss the experiments and their results. Section 5 concludes the paper.

6.2 Literature Review

This literature review first focuses on the concept of self-organized Industrial Symbiosis and its social dimensions. Next, it introduces the paradigm of agent-based modeling, and focuses specifically on agent-based models of IS development.

6.2.1 Self-organized Industrial Symbiosis

IS can be shaped by different processes, with various degrees of both intentionality and influence from external actors or environmental factors, such as public or private third-party organizations, governments, policies, and culture (Boons *et al.*, 2016). Self-organized IS are characterized by self-motivated industrial actors who intentionally or not identify by-product exchanges, or resource or service sharing opportunities. This process exploits, to various extents, an organization's capacity to acquire the necessary knowledge, and then engage and mobilize with other actors (Boons and Spekkink, 2012). It is a bottom-up process that is influenced by the industrial actors' attributes (e.g., past experience, expertise, financial situation), capacity (e.g., to engage in risky transaction, to acquire knowledge, to mobilize partners), and social environment (e.g., social interactions, local regulations, culture, social norm) as they develop and make investment decisions regarding the creation of industrial synergies. Because these attributes, capacity and factors can change over time, the processes that shape IS can also evolve as a result of individual or collective learning, the diffusion of the IS philosophy (e.g., from existing local and non-local IS cases), new social ties development, or new policy introduction (e.g., government strategies, environmental regulations, economic and innovation incentives). The next two sections briefly introduce the concepts of social embeddedness, trust and knowledge diffusion and sharing in social networks.

6.2.1.1 Social embeddedness and trust

As postulated by Chertow and Ehrenfeld (2012), Ashton and Bain (2012), Velenturf and Jensen (2016), and others, self-organized IS dynamics is generally influenced by the social embeddedness of local industrial actors, their mutual trust, and their social structure. Actors in a group are socially embedded if their behavior is influenced by other actors from the group, or by social norms that are shared within that group (Ashton and Bain, 2012). Hence, the nature and structure of social ties within a group influence IS dynamics.

For instance, Doménech and Davies (2011b) analyse the mechanisms and factors of embeddedness, such as trust, information exchange, and joint problem solving, that lead to IS development. The authors highlight the importance of trust-building and its influencing factors as central elements. Similarly, Domenech and Davies (2011a) use Social Network Analysis to study the structure of by-products exchanges in the Kalundborg IS. Although this study is limited to formal IS exchanges at a specific time (i.e., it does not analyze actual social ties, nor how the social structure evolved, nor how new actors were added to create new IS exchanges), it does give an idea of its underlying social structure: a network of industrial actors with a high degree of centrality (i.e., presence of hub actors with several connections) and a short average distance between actors (i.e., minimum number of social connections linking any two actors).

Another social characteristic of IS development is the organizations' institutional capacity to mobilize the necessary actors (e.g., industry, government, consultant, researcher) to improve the set of opportunities to initiate and implement industrial synergies (Boons and Spekkink, 2012). This capacity requires member organizations to have a certain degree of understanding of the others' expertise and their capacity to contribute to synergy creation. This aspect is addressed in the next section.

6.2.1.2 Knowledge sharing in social networks

Knowledge management (i.e., documenting and sharing of tacit and explicit knowledge within and between organizations) in IS, and how it shapes IS dynamics, has been poorly studied. Although Boons and Spekkink (2012) found that the institutional capacity to acquire and use technical knowledge did not play any role in IS development in a survey of eco-industrial parks in the Netherlands, Schiller *et al*., (2014) suggest that tacit and explicit knowledge diffusion in industrial networks, and how it is influenced by trust, should be studied insofar as it is an integral part of the social dimension of IS. In particular, Haskins (2006, pp 324) identifies "*Knowledge about, acceptance of and commitment to the concept (of Eco-Industrial Parks/IS)*" as being one of the critical factors of IS development.

In the context of social networks, knowledge diffusion and sharing, which involves information seeking and learning from others, are influenced by both the structural properties of social connections, and the intrinsic properties of these connections (e.g., strength, closeness, nature). In particular, Borgatti and Cross (2003) found that the meta-knowledge about the expertise, the perception of value, and accessibility of an organization's social connections affect positively the diffusion of that expertise between network members. As mentioned earlier, it is also a necessary factor of the institutional capacity to mobilize actors and network members. Thus, the collective learning of this meta-knowledge increases the ability to take advantage of new opportunities. In the context of industrial symbiosis, the development of such meta-knowledge can be fostered by green social networking and dedicated social media platforms as proposed by Ghali *et al*. (2016).

In brief, the diffusion and utilization of knowledge to initiate and create industrial synergies and develop IS, are poorly studied. It is not clear which aspects of knowledge sharing and utilization play the most significant role and to what extent. Yet, they are a necessary part of the diffusion of the IS philosophy and the identification of industrial synergy opportunities.

6.2.2 Agent based modeling and simulation of IS dynamics

Agent-Based Modeling (ABM) is a computational tool used (among other things) to study socio-technical, biological and economic systems by simulating the dynamics of these systems using computer simulation. This particular type of applications of ABM is referred to as Agent-Based Simulation (ABS). By modeling the individual behaviors and interactions between the key components of complex systems, and with their environment, ABS enables researchers to predict the potential impacts of small behavioral changes (e.g., how components interact, communicate, make decisions, influence one other), or environmental changes from the social, natural, or economic sub-systems (e.g., new regulations, policies, shared infrastructures, material market prices).

In this paradigm, agents are specifically designed to simulate individual behaviors observed in the system, such as reactive (i.e., programmed response to specific stimuli), goal-oriented (i.e., response planned by the agent to achieve some goals), and learning (i.e., response influenced by the agent's past experience). Agents have specific perceptions of their environment, which can be stochastic or deterministic, asymmetric or shared with other agents. They also have specific, yet limited, capacity to modify their environment or their status in the environment (e.g., location, social availability). Similarly, agents are said to be social when they are designed to communicate with others either directly (i.e., signal or message exchange) or indirectly (i.e., shared blackboard/databases, modification of their environment, perception of the others' behavior). Thus, the structure of a multi-agent collective is both dynamic and path dependent, as it emerges from both their behavior (i.e., the scope of their decisions and actions) and the way they exchange and perceive information. Although ABS is a versatile tool, its value is generally limited to the prediction of general trends of systemic behavior due to the intractable complexity of human societies and our limited ability to model this complexity. The next section introduces various IS applications of ABS.

6.2.2.1 Agent-Based Models of IS Dynamics

Previous studies have developed and used advanced tools for analyzing material and energy flows and social network structures in IS. However, very few dynamic models have been development to simulate how IS develop over time. The general principle of this approach is to model and simulate certain aspects of IS (e.g., creation of industrial synergies; exchange of knowledge, material or energy; industrial, sorting and handling processes; creation and development of social connections) to anticipate the impacts of various parameters (e.g., market price; landfill fees; social network structure) on specific performance indicators (e.g., volume of material diverted from landfill; number of active industrial synergies). Such studies are difficult or impossible using traditional social science tools, because data may simply not exist. The development of a dynamic IS model enables researchers to investigate specific situations that cannot be observed otherwise.

The ABS application proposed by Bichraoui, et al. (2013) aims to anticipate the impacts of potential conditions on IS development (e.g., number of synergies). The authors study the impacts of learning (i.e., by imitation of others' behavior) and cooperation (i.e., willingness to exchange information about output by-products). This model directly simulates by-products production and exchange flows. It considers the notion of proximity as any agent can only learn from other agents within a specific distance. It also includes the notion of plant life cycle. Here the validity of the model is assessed with a sensitivity analysis that quantitatively evaluate the impact of these factors. However, these results are not directly compared to actual data. Therefore, model validation remains largely qualitative (i.e., only general trends are validated).

Albino, et al. (2016) propose another application of ABS which aims at evaluating the capacity of simple contract mechanisms to foster a stable IS. Firm agents have the ability to select their actions (i.e., create/maintain a synergy, or do nothing) according to some utility function. They also have a local threshold to specify their willingness to commit to the creation of a synergy. Firm agents belong to any of a specific sequence of production stages. In other words, any firm from a given stage can receive by-products from the previous stage, and send its own by-products to the next stage. This model also considers trust as a parametric probability of maintaining a synergy with another firm. However, it does not evolve during simulation; it has the same value for all agents; and it has no other purpose. Furthermore, this model considers full disclosure of by-product information. In other words, all agents know what other agents produce and use, although they are only interested in the by-products they produce or use. There is also no notion of proximity, unlike in Bichraoui et al. (2013). Finally, some parameters are configured using realistic data. However, there is no reported calibration or validation of the model.

Romero and Ruiz (2014) propose an agent-based model of industrial areas that undergo conversion into an eco-industrial park. The model is based on a conceptual framework described in Romero and Ruiz (2013). In this model, agents represent firms and are described with technical (i.e., material/waste/product production/consumption, operational efficiency), economic (i.e., cost/benefit, innovativeness), and social (i.e., trustworthiness) attributes. The value of these attributes is either calculated or randomly configured according to the behavioral category of the agents (i.e., traditional, ecologic, strategic). Like in Albino, et al. (2016), the firm agents' decisions are driven by a utility function, which is a weighted average of the economic profit, the environmental impact, the strategic benefit, and the social benefit. Like in Bichraoui, et al. (2013), this model also considers firms' life cycle through firm agents' decision-making options, which are to produce, adapt (i.e., according to the social, natural or economic changes), cooperate (i.e., exchange by-product material), and manage disappearance (i.e., when the firm leave the IS). Concerning environmental changes, they are modeled as variations of the unit cost of waste flows, the unit cost of resource flows, and product demand. Therefore, the agents' adaptation capability is implemented as the updating of their attributes. This model also contains a by-product/material substitution knowledgebase used by agents to find industrial synergies. This also suggests a full disclosure of by-product/material information. The authors do not report any implementation or experimental results.

Finally, Couto Mantese and Capaldo Amaral (2017) use agent-based simulation to assess the value of several IS performance indicators for hypothetical scenarios involving simple and theoretical eco-industrial parks. This model primarily focuses on modeling material flows between company agents and a landfill agent. Although it is not based on any specific eco-industrial park, this application is original because its objective is to assess the behavior and usefulness of performance indicators. Again, its usefulness is limited by the relevance of the scenarios and the validity of the model, which are not evaluated.

ABS models of IS development are clearly in their infancy. The limited scope of these models and the lack of detailed data for calibration and validation are limitations that must be overcome to improve their usefulness and accuracy. Nonetheless, they provide valuable modeling insight and perspectives to develop more accurate models. The model presented in the next section contributes to this body of knowledge by providing a first model of social embeddedness in the context of self-organized IS.

6.3 Agent-based model

This section presents the hypothesis and the details of the proposed model. The general conceptual process is based on the Theory of Planned Behavior (TPB, Figure 6.1).

6.3.1 Hypothesis and model overview

Agents represent plants of an industrial park, which, whenever possible and under certain conditions, can create industrial synergies with each other. All plant agents (we use the term “plant” in the remainder of the paper) follow the same generic decision and interaction processes, but have their own corresponding social attributes, values, and levels of knowledge. The proposed self-organized IS structure is heterarchical. Thus, plants exchange knowledge only with their social contacts, and are not aware of what happens in the network as a whole.

Unlike the models presented earlier, this model does not consider explicitly waste and by-product flows. Instead, potential industrial synergies are randomly pre-defined between pairs of plants. Each of these potential synergies also specifies for each of the concerned plants some investment they must make to operationalize the synergy. These investments, along with random revenues, condition the profitability of the synergy. This modeling approach allows us to control the number of potential synergies in any given network without having to model flows and address their input/output compatibility.

We also do not consider the active search for synergies and the notion of proximity. Instead, we consider serendipitous identification of industrial synergies within the direct social contacts of plants. Consequently, along with the pre-definition of potential synergies, we also pre-define a network of social contacts and introduce randomly during simulation new contacts between plants. Therefore, if a potential synergy is pre-defined between two plants that are never in contact during simulation, then this synergy is never created.

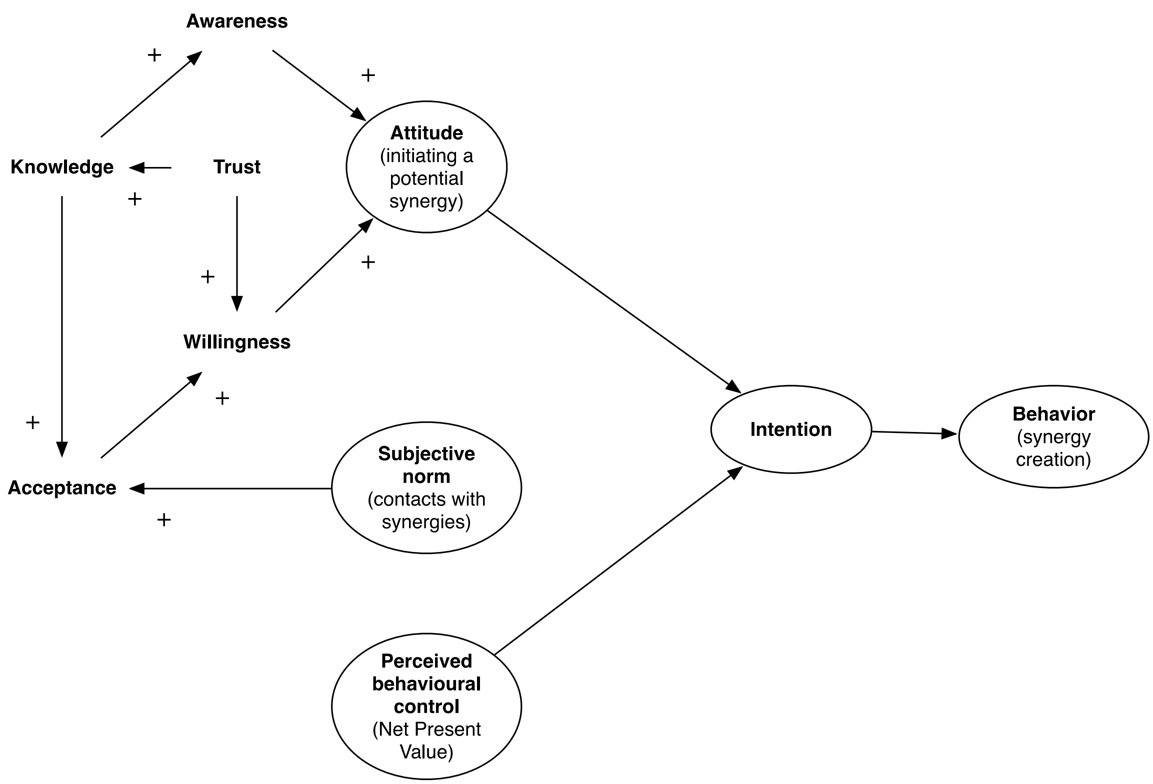


Figure 6-1: General Planned Behavior of plant agents

Thus, plants only rely on their social contacts and the diffusion of the IS philosophy to identify potential synergies. This diffusion process is modeled as both internal (i.e., within a plant's social contacts) and external processes (i.e., when plants learn from other sources). The internal diffusion process is a function of the trust plants have for each other. Unlike Albino, *et al.* (2016), for whom trust is an attribute of the network, and Romero and Ruiz (2014), for whom trust is an attribute of the plants, we model trust as an attribute of a directed social contact. It is the perception of a given plant of the level of trustworthiness of another plant. It is non-symmetrical and influenced by its reputation within the plant's social contacts.

Finally, knowledge is modeled as a bounded variable representing the level of acquaintance of any plant with respect to the IS philosophy. The diffusion of knowledge from one plant to another is a function that only allows transfer from a higher level of knowledge towards a lower level. Similarly, we do not model knowledge accessibility constraints nor the cost of knowledge sharing. Knowledge is always available between socially connected plants.

Concerning the plants' range of actions, it is limited to knowledge transfer and the creation, or not, of industrial synergies. First, knowledge transfer involves the updating of knowledge and social parameters. To do so, time is discretized, and plants' attributes at any time period are computed using mathematical functions (see details below), their attributes, and other attributes from their environment (i.e., financial parameters, other agents' attributes) at the previous time period. Next, the creation of a synergy follows a decision process that first requires the identification of a potential industrial synergy, which we refer to as *awareness* (Figure 6.1). If a plant's knowledge level is greater than a particular threshold, then it becomes aware of any existing potential synergies within its own network of contacts and informs the potential partner of its existence. Next, plants must both be willing to create a partnership with each other. We refer to this as willingness (Figure 6.1). It is influenced by trust, as well as how many synergies have been created within a particular plant's social contacts, which represent subjective norm in the TPB framework. Both awareness and willingness define the plants' attitude toward creating - or not- the potential synergy. Once the potential synergy is known by both potential and willing partners, they have access to investment information (i.e., cost, anticipated revenues). They both use it to compute the net present value of the synergy to determine if it is profitable. This defines the perceived behavioral control of both plants involved (Figure 6.1). If and only if both partners find it profitable, then the synergy is created.

6.3.2 Plant attributes and behaviour

The plants' attributes describe their characteristics at any given time period, such as their knowledge level, their level of social influenceability, their level of social interaction with other plants, or their willingness to commit to the creation of an industrial synergy. Some of these attributes are dynamically computed (i.e., variables), while others are pre-determined (parameters). The following sections describe in details the different components of the model.

6.3.2.1 Social contacts

Each plant could potentially have a social contact with any other plants. We assume that a social contact represents any social relationship between, at least, any two of the managers of two plants. We also assume that social relationships can influence management decisions. These social contacts are, by nature, dynamic. They can be created during simulation; their attributes can evolve in time; and they can be transformed into an industrial synergy. Their existence is modeled as a binary variable γ_{ij}, which represents a social contact between plant i and j, with $i, j \in P$, P being the set of all plants, and $\gamma_{ij} = \gamma_{ji}$. Variables γ_{ij} for all $j, i \in P$ represent the social network structure of P.

$$\gamma_{ij} = \begin{cases} 1 & if\ plant\ i\ and\ j\ have\ a\ social\ contact \\ 0 & otherwise \end{cases}$$

Next, we define the notion of social network of a plant, or more simply its contacts, as the set of plants C_i with whom plant i has a social contact with (i.e., $C_i = \{ j \mid j, i \in P,\ \gamma_{ij} = 1, \}$). The set of all social contacts of any plant is bounded, as we only consider here social contacts within P (i.e., $C_i \subset P, \forall i \in P$). They are characterized by both their structure (γ_{ij}, $\forall i, j \in P$), and their nature, which is represented by other variables and parameters defined below.

6.3.2.2 Potential industrial synergy

A potential industrial synergy is modeled as the existence of a potential industrial synergy between two plants. It is a binary parameter s_{ij}, which represents the existence or absence of a potential industrial waste exchange between plant i and j, with $i, j \in P$, and $s_{ij} = s_{ji}$. Variables s_{ij} for all $\forall\ j, i \in P$ represent the set of potential industrial synergies within P.

$$s_{ij} = \begin{cases} 1 & if\ plant\ i\ and\ j\ have\ a\ potential\ industrial\ synergy \\ 0 & otherwise \end{cases}$$

Because these potential synergies are not necessarily known at any time, unless specific conditions are met, we must also define the notion of *awareness*, which represents whether or not the plants involved are aware of any potential exchanges. Thus, we also define binary variable A_{ij}^{t}, which represents the awareness of plant *i* at time *t* of the existence/absence of a potential synergy with plant *j*, with $i, j \in P$, and $A_{ij}^{t} \neq A_{ji}^{t}$. As explained later, the value of A_{ij}^{t} is a function of the knowledge of plants *i* and s_{ij}.

In order to model the existence of a created synergy, we also define variable S_{ij}^{t} to specify whether two plants *i* and *j* share an industrial synergy at time period *t*, with $S_{ij}^{t} = S_{ji}^{t}$.

$$S_{ij}^{t} = \begin{cases} 1 & if\ plant\ i\ and\ j\ have\ an\ industrial\ synergy\ at\ time\ period\ t \\ 0 & otherwise \end{cases}$$

6.3.2.3 Trust

We adopt Yu and Singh (2000) formal definition of trust. Hence, the trust rating assigned by plant *i* to *j* at time *t* is a continuous variable ${T_{ij}}^{t}$, with ${T_{ij}}^{t} \in [-1,1]$ (i.e., minimum and maximum trustworthiness). At the beginning of each time period, each plant updates its rating of other plants using Equations (1) and (2) to model how trust evolves over time and how it is propagated through social contacts. We use several parameters to describe how much each plant can be influenced by its own set of contacts, and how much trust can be influenced by other serendipitous external events.

$$\mathrm{T_{ij}}^{t+1} = \begin{cases} \min[\mathrm{T_{ij}}^{t} + \beta_i\left(\overline{\mathrm{T}_{ij}^{t}} - \mathrm{T_{ij}}^{t}\right) + \mathrm{d_{ij}}^{t}; 1] & \text{if} \quad \mathrm{T_{ij}}^{t} \leq \overline{\mathrm{T}_{ij}^{t}} \\ \max[-1; \mathrm{T_{ij}}^{t} + \beta_i\left(\overline{\mathrm{T}_{ij}^{t}} - \mathrm{T_{ij}}^{t}\right) + \mathrm{d_{ij}}^{t}] & \text{if} \quad \mathrm{T_{ij}}^{t} > \overline{\mathrm{T}_{ij}^{t}} \end{cases} \qquad (1)$$

$$\overline{T_{ij}^{t}} = \frac{\sum_{k|k \in C_i \cap C_j} {T_{kj}}^{t}}{|C_i \cap C_j|} \qquad (2)$$

with

$i, j \in P$

$T_{ij}{}^{t}$ trust rating assigned by plant *i* to *j* at time *t* with $T_{ij}{}^{t} \in [-1,1]$;

$\overline{T_{ij}^{t}}$ reputation of plant *j* assigned by common contacts of plants *i* and *j* at time *t*;

$|C_i \cap C_j|$ number of common social contacts of plant *i* and *j*

β_i social influenceability level of plant *i* with $\beta_i \in [0,1]$;

$d_{ij}{}^{t}$ trust increment assigned by plant *i* to *j* at time *t* due to serendipitous social event between *i* to *j* with $d_{ij}{}^{t} \in [-1,1]$.

In brief, Equations (1) and (2) define trust at time period t as a continuous variable. It is influenced by the past trust value of agent j, its reputation (w.r.t. the common contacts of agents i and j) and the level of influenceability of agent i, and other serendipitous social events.

6.3.2.4 Knowledge and knowledge transfer

Knowledge is modeled as an aggregated level of awareness 〖K_i〗^t∈ [0,1] of plant i with respect to the IS philosophy. We assume that, all things being equal, the higher this level of knowledge, the more likely a plant will be to consider the creation of an industrial synergy. This assumption means that if managers are either aware of the IS philosophy or the existence of industrial synergy practices in their own industrial sector, they are more likely to have a positive attitude towards adopting such a solution for their own industrial needs. We also assume that this knowledge can only be gained through knowledge acquisition (e.g., learning or hiring of experts), or sharing, which is a function of the social interaction intensity and trust levels within the social contacts of a plant. To do so, plants also update at the beginning of each time period their knowledge level according to Equation (3).

$$K_i{}^{t+1} = min\left(1; K_i{}^{t} + \beta_i . \sum_{j \in C_i | T_{ij}{}^{t} \geq \tilde{t_i}} \widehat{K_{ij}}{}^{t} + l_i^t\right) \quad (3)$$

with

${K_i}^t$ knowledge of plant *i* at time *t* with ${K_i}^t \in [0,1]$

$\widehat{K_{ij}}^t = \max\left(0; \sigma_{ij}^t\left(K_j^t\text{-}K_i^t\right)\right)$ with $i, j \in P$

$\widehat{K_{ij}}^t$ maximum knowledge increment of plant *i* from agent *j* at time period *t*;

l_i^t knowledge gain at time period *t* due to learning or the hiring with $l_i^t \in [0,1]$;

σ_{ij}^t social interaction intensity of plant *i* and plant *j* at *t* with $\sigma_{ij}^t \in [0,1]$;

$\breve{t_i}$ minimum trust threshold of plant i to consider knowledge sharing or a waste exchange with another plant;

Equation (3) defines the knowledge level of a plant at any given time period, as its knowledge at the previous time period, plus the knowledge gained from social interactions within its trusted contacts, plus the knowledge gained from learning/hiring.

Next, based on Equations (1) and (3), we define the concept of awareness of a potential industrial waste exchange introduced earlier is defined as:

$$A_{ij}^t = \begin{cases} 1 & \text{if } {K_i}^t \geq \breve{k} \text{ and } s_{ij} = 1 \\ 0 & \text{otherwise} \end{cases}$$

with

$\breve{k}$ minimum knowledge threshold required to be aware of a potential exchange. = 1.

$\breve{k}$ represents the fact that plants must possess a minimum level of understanding of the IS philosophy to be aware of the existence of any potential synergy. We assume that it is the only necessary condition although in practice, some technical expertise may be involved. Because being aware of the existence of a potential synergy, does not guarantee the plant is ready to adopt that solution, we introduce here the notions of acceptance and willingness.

6.3.2.5 IS Acceptance and Willingness to commit

The willingness of a plant to commit with another plant represents the non-financial attribute of its willingness to create a synergy with this plant. It is a function of the IS acceptance level of that plant and its trust toward the other plant (Equation 5). The IS acceptance level represents how much a plant is willing to invest in a synergy regardless of its partner. It is influenced by the percentage of his/her social contacts with a synergy (subjective norm), and its recent knowledge acquisition (Equation 4). We did not, however, model the negative impact of synergy creation failure. This results in a strictly increasing level of knowledge and acceptance functions as shown in Equations (3) and (4). We also introduce the notion of self-confidence of a plant, which allows us to model various attitude toward risk with respect to any knowledge acquisition between two consecutive periods.

$$B_i{}^{t+1} = \min\left(1;\ B_i{}^t + \beta_i.\frac{\sum_{p \in C_i} \widehat{S_p^t}}{|C_i|} + \mu_i.(K_i^t\text{-}K_i^{t\text{-}1})\right) \tag{4}$$

$$W_{ij}^t = \begin{cases} B^t & \text{if } \ T_{ij}{}^t \geq \breve{t_\iota} \ \text{ and } \ \mathrm{A}_{\mathrm{ij}}^{\mathrm{t}} = 1 \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

with

$$\widehat{S_p^t} = \begin{cases} 1 & \text{if plant } p \text{ has an industrial synergy with any plant at time period } t \\ 0 & \text{otherwise} \end{cases}$$

$B_i{}^t$ Acceptance level of plant *i* to create a synergy at time *t* with $B_i{}^t \in [0,1]$;

W_{ij}^t willingness to commit of plant *i* to create a synergy with plant *j* at time *t*

μ_i self-confidence of plant *i* to use its knowledge;

$\breve{w}$ minimum level of willingness to commit to any synergy creation.

The willingness of plant *i* to commit with *j* at *t* takes a non-zero value if and only if *i* is aware of a potential synergy with *j*, and if *i* trusts *j* beyond threshold $\breve{t}_i$. Furthermore, it must be larger than $\breve{w}$ for any plant to commit to any synergy creation. It is also a function of its acceptance level.

6.3.3 Investment decision

$$R_{producer,t} = V_{exch,t}.\left(C_{landfill,t} + P_{waste,t}\right) \tag{6}$$

$$R_{buyer,t} = V_{exch,t}.\left(P_{resource,t}\text{-}P_{waste,t}\text{-}C_{transport,t}\right) \tag{7}$$

with

$R_{producer,t}$ net cash flow of the producer during period *t*;

$R_{buyer,t}$ net cash flow of the buyer during period *t*;

$V_{exch,t}$ volume of waste/by-product exchanged between plants *i* and *j*;

$C_{landfill,t}$ landfill cost during period *t*;

$P_{waste,t}$ price of waste/by-product during period *t*;

$P_{resource,t}$ price of new resource during period *t*;

$C_{transport,t}$ transportation cost during period *t*;

$R_{producer,t}$ includes landfill cost savings and revenues from the sale of its waste. In practice, the situation is more complex and can include contracts (Albino, *et al.*, 2016). Next, $R_{buyer,t}$ includes the savings from not having to buy new resources, minus the cost of the alternative waste/by-product that must be acquired and transported. Using these values, we calculated the Net Present Value with Equation (8).

$$NPV_{i,j} = \sum_{t=0}^{N} \frac{R_{i,t}}{(1-d)^t} \tag{8}$$

with

$NPV_{i,j}$ Net Present Value of the potential industrial synergy between plant *i* and *j*;

d discount rate

N number of periods to pay off the initial investment.

6.3.4 Plant behaviors

At the beginning of each time period, each plant executes sequentially two processes: trust and knowledge update (Figure 6.2), and synergy creations (Figure 6.3). First, trust and knowledge update consists of updating trust, knowledge, and acceptance variables. This is done for all social contacts of the plant. Next, synergy creation consists of a series of tests and computations that aim at: (1) identifying if the plant is aware of the potential synergy with any plant of its social network (i.e., list of contacts); (2) computing if the plant is willing to commit to an IS within its social network; and (3) computing the profitability of the potential synergy. If all tests are positive, then the synergy is created. If not, the process continues for all its social contacts. Once both processes have been executed, new random social contacts are added globally, and the social networks of the involved plants are updated.

Each computation only involves data calculated at previous periods. The simulation process starts with initial value and ends when a certain number of time periods has been reached. Data are then collected for analysis.

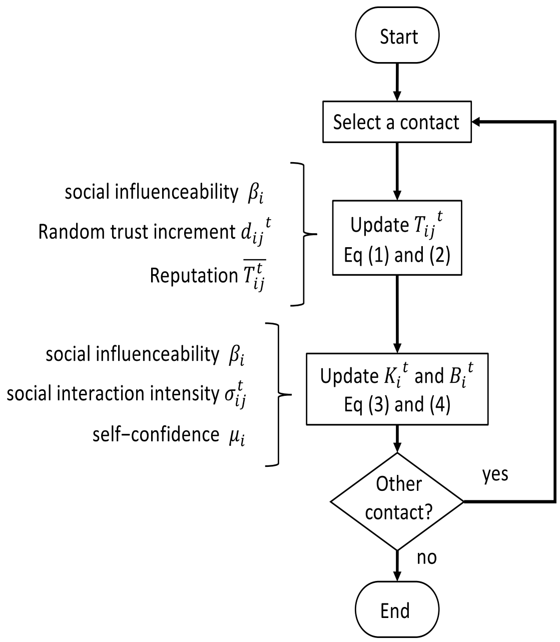


Figure 6-2: Trust and knowledge update process

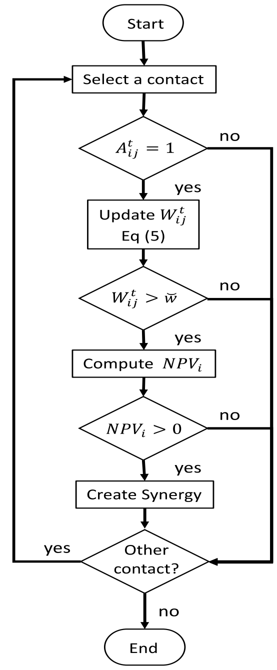


Figure 6-3: Industrial synergy creation process

6.4 Model implementation and experiments

This model was implemented with NetLogo. The next section presents simple calibration and validation experiments we performed.

6.4.1 Model Initialization and calibration

To evaluate the general behavior of the model, we performed a sensitivity analysis with parameters β_i, μ_i, σ_{ij}^t and $\breve{t}_i$ to study their influence on the average number of synergies created.

To do so, we analyzed the impact of each parameters with 200 plants and random social networks, by setting all other parameters to its midpoint value, and by running 30 simulation replications for several values along its entire range (e.g., 0, 0.25, 0.5, 0.75, 1). Then, we averaged the results for each value point.

First, we observed that their influence is non-linear. When social influenceability β_i increases, the average number of synergies starts increasing at 0.25, and increases almost linearly after. Concerning self-confidence μ_i, the average number of synergy increases almost linearly and reach a plateau around 0.75. Concerning social interaction intensity σ_{ij}^t, the average number of synergy also increases with a maximum around 0.75. Finally, the minimum trust threshold $\breve{t_i}$ is the only parameter that does not positively correlate with the average number of synergy, which decreases more or less linearly as it increases.

Although it is not possible to quantitatively calibrate these parameters with actual data, their influence on the number of created synergies is consistent with the original design objectives of the model. In particular, because the minimum trust threshold (i.e., minimum expected level of trustworthiness) affects both knowledge sharing and the willingness to commit to create a synergy, the lower this threshold (i.e., when plants are more likely to trust each other), the more synergies are created. As explained by Albino, *et al*., (2016), this coincides with general empirical observations.

For all other experiments, these parameters are drawn randomly using a uniform distribution with limited ranges of values to create a relatively homogeneous population of plants with respect to their social characteristics (see Table 6.1 and Table 6.3).

Table 6-1: Simulation parameters

Notation	**Description**	**Ranges of parameters**	
	Social Parameters		
$T_{ij}^{t=0}$	initial trust rating assigned by plant *i* to *j*	[-1; 1]	
${K_i}^{t=0}$	Initial knowledge level of plant *i*	Experiment *a* [0; 0.5]	Experiment *b* [0; 0.25]
l_i^t	non-social knowledge gain of plant *i* at period *t* due to learning or hiring	Experiment *a* [0; 0.1]	Experiment *b* [0; 0.2]
β_i	social influenceability level of plant *i*	[0.5; 1.0]	
μ_i	self-confidence of plant *i*	[0.5; 1.0]	
σ_{ij}^t	Social interaction intensity between plants *i* and *j* at period *t*	[0.5; 1.0]	
$\breve{t}_i$	minimum trust threshold of plant *i* to consider knowledge sharing or a synergy with others	[0.25; 0.75]	
$\breve{k}$	minimum knowledge threshold to be aware of a potential synergy	[0.75; 1.0]	
${d_{ij}}^t$	trust increment assigned by plant i to j at time t due to serendipitous social events	[-1; 1]	
$\breve{w}$	minimum willingness threshold of plant *i* to consider creating a synergy with others	[0.5; 1.0]	

Table 6-2: Economic parameters

Economic Parameters		
$I_{i,j}$	Initial investment of synergy between plant *i* and *j*	\$1000
d	discount rate	10%
$V_{exch,t}$	Anticipated volume of exchanged by-products at period *t*	[1000; 10 000]
$C_{landfill,t}$	landfill cost	[\$70; \$90]
$P_{resource,t}$	selling price of residual	[\$1; \$150]
$C_{transport,t}$	Transport cost	4\$/ton
$P_{resource,t}$	Resource price	[\$1; \$150]

6.4.2 Experiments

In order to illustrate how this model can be used to predict the impact of specific social structures and dynamics on IS development, we designed an experiment to study the impact of several factors on the number of synergies created over time, including the number of potential synergies, the number of new social contacts per period, and the type of social network. The next section presents the design of these experiments.

6.4.2.1 Design of experiment

As shown in Table 6.1, we performed two series of experiments to test two different general knowledge configurations (i.e., experiment *a*, medium average initial knowledge level with small non-social gains; experiment *b*, low average initial knowledge level with medium non-social gains). Next, for each of them, three experimental factors were defined separately (Table 6.3). The potential synergy level represents the general potential to create a dense IS. It is the percentage of pairs of plants with a potential synergy. Some parks may have more potential synergies than others. In practice, this can even be influenced by adding specific plants with high synergetic potential with the plants already in the IS.

The two other factors represent respectively the social dynamics and social structure between plants. More specifically, the number of new social contacts per period is a proxy of the social dynamics. A higher level of new social contacts can be used to simulate the use of a green social media without input-output matching function, or an eco-industrial park with an extension activity program or coordinator in industrial ecology. New social links are randomly added, although they do respect the type of structure of the initial social network. This aspect is developed next.

Table 6-3: Experimental design

		Number of new social contacts per period		
		0%	***0.5%***	***1%***
Potential synergy level	***5%***	*scale-free*	*scale-free*	*scale-free*
		Random	*Random*	*Random*
	10%	*scale-free*	*scale-free*	*scale-free*
		Random	*Random*	*Random*
	15%	*scale-free*	*scale-free*	*scale-free*
		Random	*Random*	*Random*

All other factors were drawn randomly for uniform distributions with specific ranges of values as presented in Table 6.1 and Table 6.2. Furthermore, in all experiments, we consider an industrial park of 50 plants. The number of new social contacts per period is expressed as a percentage of all possible social contacts within a set of 50 plants (i.e., 50 x 49 / 2 = 1225). We consider 3 levels (0%, 0.5%, 1%). The potential synergy level is also expressed as a percentage of all possible pairs of plants. Again, we consider 3 levels (5%, 10%, 15%). Finally, concerning the network structure, we consider two types: scalefree and random networks, as described in the next section. We used a factorial design, so all combinations of factors were simulated 50 times for a total of 36 experiments and 1800 simulation replications (see Table 6.3).

6.4.2.2 Network types

We consider two types of network structures to describe social structures: random and scale free networks. Random graphs are generated using random probability distribution, in which each edge of a network has a uniform and independent probability of occurrence. We used a probability of 0.02 in order to match the number of initial social links in the scale-free network. Thus, the expected number of social contacts with 50 plants and a probability of 0.02 is 49, which represents 4% of all possible social contacts.

Scale free networks refers to a class of networks exhibiting power-law degree distribution. In other words, the fraction $f(m)$ of nodes with *m* links decrease with *m* according to Equation (9).

We built scale-free networks by progressively adding a node *n* from the initial set of 50 to the network, and by adding a link between node *n* and another node *i* from the network with a probability P_{ni} based on the Barabási-Albert model (Equation 10).

$$f(m) \approx a.m^{-k} \tag{9}$$

$$P_{ni} = \frac{k_i}{\sum_j k_j} \tag{10}$$

with

k_i number of social links of plant *i*.

This construction process creates scale-free networks with 49 links. It was also used to add social links during simulation. Scale free networks better represent social structures in which there are many people with few connections, and few people who are very connected.

6.4.3 Results and discussion

The experimental output studied is the number of synergies initiated each year. The results of the repetitions of each experiment, which are simulated instances of IS dynamic, were averaged for each year. Thus, the graphs shown in the next sub-sections represent an average dynamic for a specific set of conditions.

6.4.3.1 Impact of potential industrial synergy level

Figure 6.4 (a, c) illustrates for 0.5% of new social links and the knowledge configuration of experiment *a* (i.e., average initial knowledge level: 0.25; average non-social knowledge gain: 0.05; average minimum knowledge threshold: 0.875-), how the average number of synergy evolves for both types of network. We can see that, on average, there is no synergy created before year 5. With the knowledge configuration of experiment *a*, knowledge sharing through social links was necessary to reach the minimum level of knowledge required in 5 years on average, and so, regardless of the level of potential synergies. This validates the intended function of knowledge as a constraint in the discover of potential synergies. Figure 6.4 (a, c) also shows that a higher level of potential synergy increases the number of industrial synergies initiated, which is to be expected because the higher the number of potential synergies, the larger the overlap of the sets of potential synergies and social links. The obvious practical implication of this observation is that industrial parks with a higher level of input-output compatibility are more prone to develop synergies. It also implies that the selection and addition of new plants or industries with high input-output compatibility with existing plants in the park may eventually lead to more synergy creation in the right social conditions.

Next, although new social links are added linearly, their impact is not, as synergy creation slows as time progresses. Again, this lag can be linked to learning and the constraining effect of knowledge. Indeed, as the average overlap between social links and potential synergies increases linearly, it takes time for knowledge to reach the minimum level required for these potential synergies to be discovered. Once this level is achieved, many of these synergies are implemented rapidly until there is no new potential synergy to discover. Again, the obvious practical implication of this observation is that an industrial park with well-developed knowledge in IS philosophy is more likely to take advantage of its social structure to create actual synergies, which also coincide with empirical observations.

This general observation is also shown in figure 6.6 (a) for both types of network and no new social links added, where no new synergies are discovered after 10 years. It is also suggested in figure 6.4 (b and d), where the number of initiated synergies is expressed as a percentage of the number of potential synergies. It shows that this measure of IS dynamics is independent of the level of potential synergies, which suggests, as discussed in the next section, that social dynamics (e.g., social interaction level, number of new social links, network structure, trust level) and learning (e.g., from non-social learning or hiring) are factors constraining the ability of the entire network to identify potential synergies.

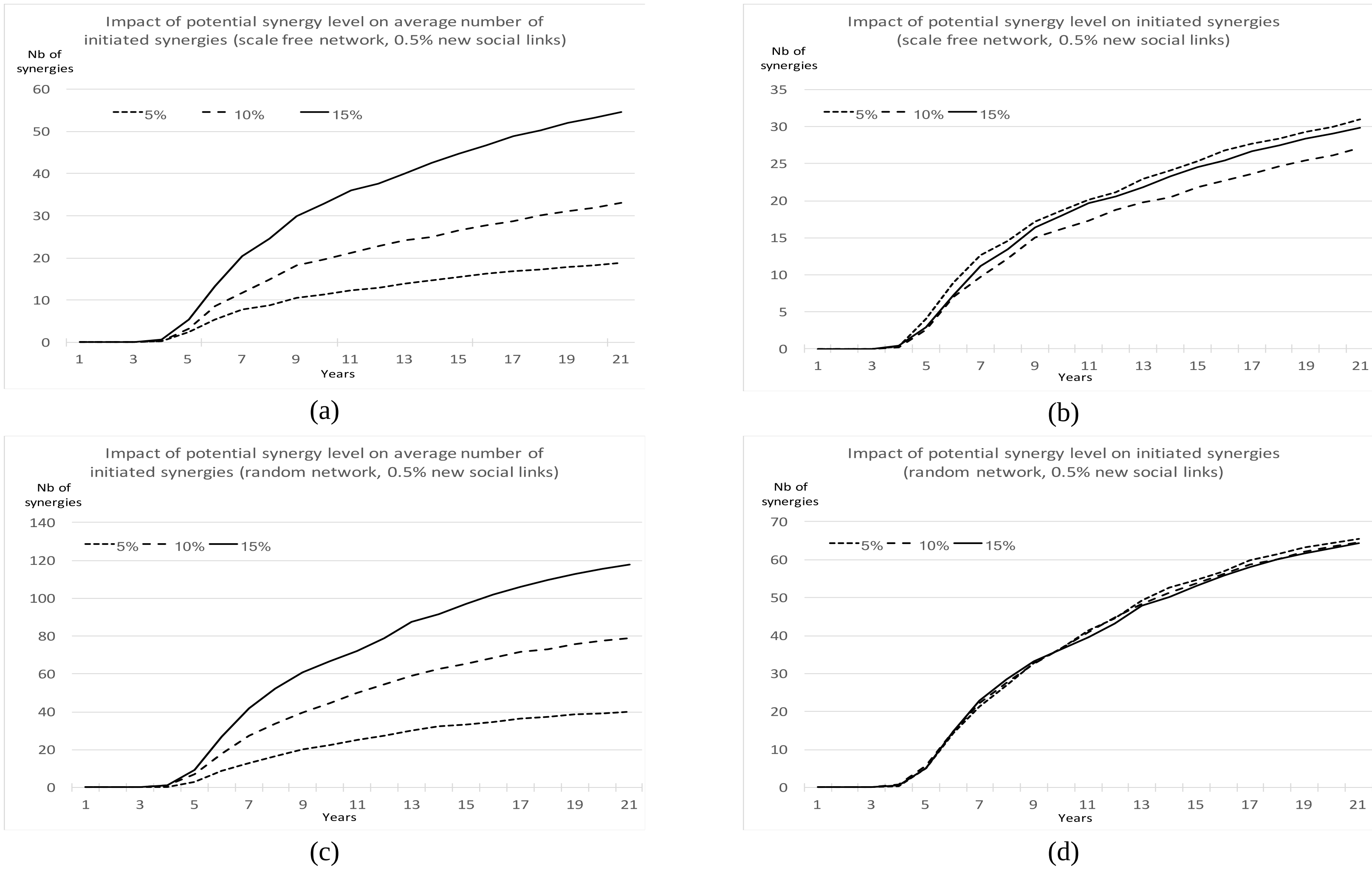


Figure 6-4: Impact of potential synergy level on the number of synergy initiated (a, scale free network; c random network) and the percentage of potential synergy initiated (b scale free network; d random network)

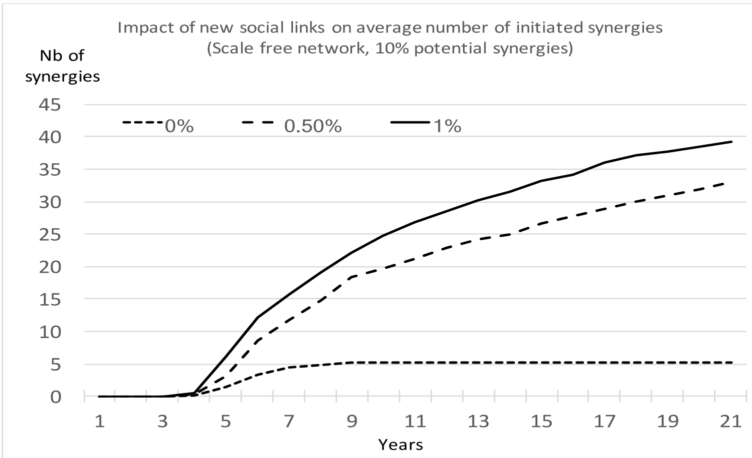
6.4.3.2 Impacts of social dynamics

Figure 6.5 (a, b) shows for 10% of potential synergies and both types of networks, that the higher the number of new social links, the higher the average number of initiated synergies. These results are similar for all scenarios. Even a slight increase of social activity from 0% to 0.5% increases the likelihood of creating synergies. However, a similar increase from 0.5% to 1% has a much smaller impact for both types of networks.

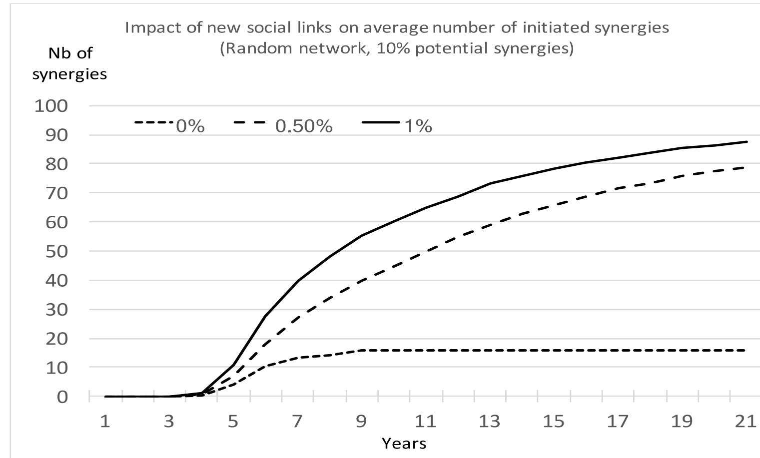
This suggests that a higher level of social dynamics (i.e., number of new social links) significantly promote the creation of synergies, and so, for all three levels of potential synergies (Table 6.4). The practical implication is that industrial parks with low level of social interactions might benefit from social mediation to increase social connectivity and promote synergy creation, although its impact may vary according to its pre-existing social dynamics and structure, and its synergistic potential. However, these results remain theoretical. More experiments are needed to investigate this phenomenon, which suggests that, in purely self-organized IS, both learning and social dynamics are enablers of synergy creation.

Table 6-4: Impact of social dynamics on the total percentage of potential synergy initiated (random network)

		Number of new social links		
		0%	**0.5%**	**1%**
Potential synergy level	**5%**	12.4%	65.6%	72.8%
	10%	13.0%	64.6%	71.9%
	15%	10.8%	64.3%	74.8%
Average		**12.1%**	**64.8%**	**73.2%**



(a)



(b)

.

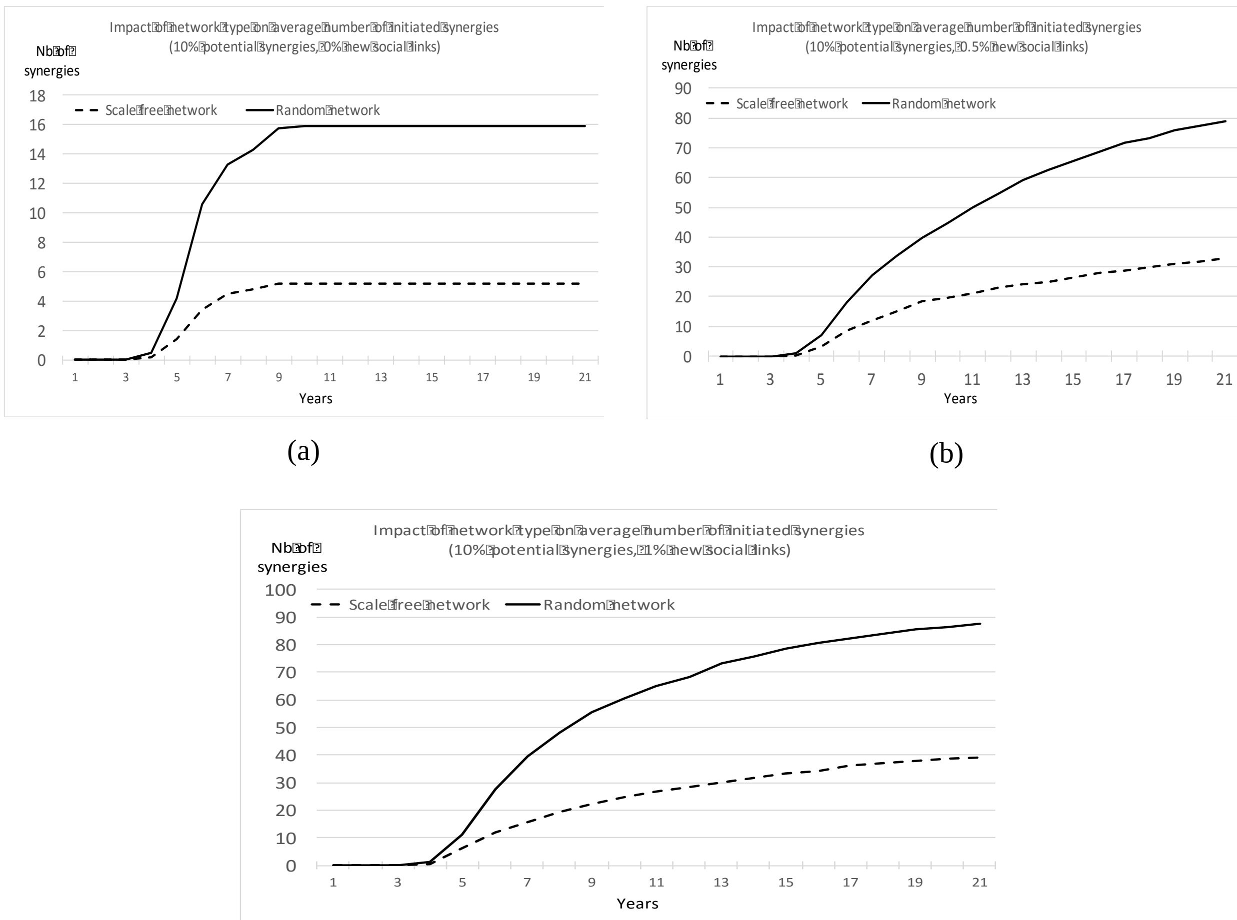
Figure 6-5: Impact of social dynamics on the number of initiated synergies

6.4.3.3 Impact of network type

Figure 6.6 (a, b, c) presents the impact of types of network structure for, respectively, 0%, 0.5% and 1% of new social links. We can see that random networks always outperform scale-free networks. This is true for all tested scenarios and knowledge conditions. However, this result must be investigated further insofar as the network structure of potential synergies was random, which implies that the hub-like structure of scale-free social networks has a smaller overlap with random networks of potential synergies, which, in turn, affects its dynamics. Furthermore, synergy networks are not necessarily random as shown by Domenech and Davies (2011a) who mention a hub-like structure in the case of the Kalundborg study. Consequently, although this results shows that the type of social structure affects IS development, it is necessary to analyze further the combined impact of IS social and potential synergetic structures. In particular, more simulation experiments with realistic initial network structure conditions are needed.

6.4.3.4 Impacts of Knowledge conditions

Figure 6.7 presents the impact of different knowledge conditions (i.e., initial knowledge level and knowledge gain due to learning or hiring) from experiments a and b, for 0% new social link, scale free network, and 10% potential synergy. First, there is no difference between both initial conditions as soon as new social links are added, which suggest that, for the tested scenarios, social dynamics dominates initial knowledge and non-social learning conditions. However, a small difference appears with no new social links. As expected, we can see that a smaller level of initial knowledge tends to delay slightly the creation of synergies (it takes more time to become aware of potential synergies), although the end results are comparable. This is observed for all level of potential synergies and both types of network. Similarly, although this shows that knowledge sharing can be an effective means of spreading the IS philosophy, these theoretical results require more in-depth analysis of the impact of initial knowledge level and non-social learning on IS development.



(a) (b)

(c)

Figure 6-6: Impact of network type (10% potential synergy level; (a) 0%, (b) 0.5%, (c) 1% of new social links

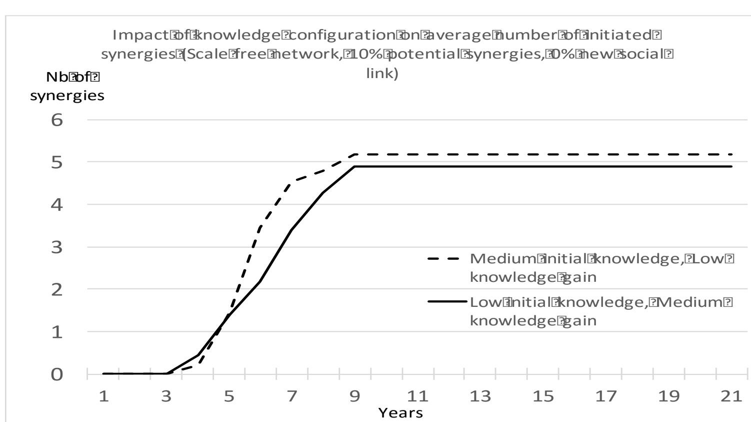


Figure 6-7: Impact of knowledge conditions

6.5 Conclusion

In this paper, we proposed the first dynamic model of social embeddedness in self-organized IS. This model represents social embeddedness as a set of dependent variables describing how trust, reputation and knowledge sharing evolve in different social dynamics and structure and, how they influence the IS development. We also illustrate the potential outcome and applications of this model in terms of capacity to predict the impacts of social dynamics and structure to promote the development of IS. Finally, we also identify specific directions to collect actual data, and promote multi-disciplinary studies, in order to better configure and validate such models and improve their experimental accuracy.

However, although the experiments reported here show how IS socio-technical attributes can emerge from the interactions and behavior of individual plants, this model remains simplistic and many assumptions were made. The experiments also illustrate how such a model could be used as a complementary tool for case studies, surveys, and other empirical studies, which provide the knowledge required to model appropriately.

There are many different directions to improve this model. For instance, we can address supply stability, both in quality and quantity, which is required to consider by-product exchange. Furthermore, we can also consider the dynamic introduction (or closure) of plants that can be more or less proactively added to create more synergies. Along this line, we can also improve the discrete modeling of time and model IS development more accurately, per month or even week, along with the modeling of exchange flows, and their price and cost fluctuations. Other factors could also be included such as purchase contracts. Finally, we should also study the actual network structures of synergies in IS, and simulate these structures to improve the accuracy of our model.

CHAPITRE 7 DISCUSSION GÉNÉRALE

L'écologie industrielle est une approche multidisciplinaire qui étudie les systèmes à l'échelle d'un parc industriel, d'une région, ou même au niveau national dans le but d'optimiser la gestion des flux de matière et d'énergie et le partage des ressources et services grâce à la mise en œuvre de synergies et de mutualisations de ces flux. Comme l'illustre la diversité et complémentarité des contributions de cette thèse, c'est un domaine de recherche et de pratique encré dans les domaines (entre autres) du génie, des sciences sociales, de l'administration des affaires, mais aussi du développement logiciel.

La littérature étudiée dans cette thèse a présenté plusieurs formes et dynamiques de symbioses industrielles, du modèle purement auto-organisé et non encadré, au modèle purement planifié et rigide, au modèle facilité, dans lequel une tierce partie, ou un média social tel que proposé dans cette thèse, sert de point de relais ou pivot entre les différentes parties prenantes (publiques et privées) afin de (1) supporter le partage de la philosophie et des connaissances des symbioses industrielles, et (2) identifier des compatibilités et opportunité de synergies industrielles.

L'idée originale première de cette recherche est celle qu'un réseau social vert (Green Social Networking), dans la fonction est de supporter le partage des expériences et expertises, d'engendre un changement de mentalité et la diffusion de la philosophie des symbioses industrielles, et éventuellement la création de nouvelle synergie industrielle.

À l'aide d'une approche de modélisation conceptuelle du processus d'initiation des synergies industrielles, nous avons mis en évidence le rôle potentiel des réseaux sociaux dans l'initiation et le développement de synergies industrielles. Notamment, la présentation des diverses fonctions existantes des médias sociaux existants a permis de pour mieux comprendre leur fonctionnement ainsi que leurs apports par rapport aux outils traditionnels (Grant., 2010).

Le cadre qui a été proposé dans cette thèse vise à guider les praticiens dans le développement de plates-formes de média social de prochaine génération, ainsi que leurs modèles d'affaires. Ainsi, les travaux futurs de ce sujet incluent le développement d'une plate-forme GSN sur la base d'un prototype programmé dans le cadre de ce projet (non-rapporté dans cette thèse). Une telle plate-forme Web innovante pourrait ainsi permettre aux entreprises productrices et utilisatrices de résidus d'identifier des entreprises similaires ou complémentaires, d'avoir accès à une expertise et des connaissances en ligne, de suivre en temps réel les nouvelles en écologie industrielle, d'avoir des connections professionnelles de différents niveaux, d'avoir une évaluation qualitative des aspects économique, logistique et technique de certains types de partenariat et synergie industrielle, d'avoir des conseils méthodologiques pour la mise en œuvre d'une synergie (par exemple, au niveau réglementaire, des conseils pourraient aider les entreprises à assurer leur conformité réglementaire des synergies), d'avoir un agent intelligent (facilitateur) afin de faciliter la découverte et l'initiation de synergie, etc.

Un tel réseau social vert devrait être conçu de manière à inciter les entreprises à modifier leurs comportements ou à en adopter de nouveaux (design persuasif, Fogg, 2003, Bastien, 2012). C'est un des moyens d'encourager les entreprises à changer d'attitude vis-à-vis des problématiques liées à l'optimisation de l'utilisation des ressources. Il devrait également être testé auprès d'utilisateurs cibles ou d'experts. Les informations recueillies permettent de tester et valider la plateforme (dont l'évaluation des émotions, l'évaluation experte, l'inspection cognitive et les tests utilisateurs), ou de proposer des recommandations d'amélioration.

Un aspect important du développement d'un tel réseau social vert concerne le besoin de structurer et faciliter l'échange d'information et ainsi d'offrir aux utilisateurs, par exemple, des synthèses des commentaires et messages échangés, des rapports, des indicateurs de performances clés et des tablex et graphiques mettant en évidence les zones d'opportunités de synergies.

À moyen et long terme, la conception d'une telle plateforme avec certaines fonctions sociales destinées à l'opérationalisation du développement durable pourrait ne pas être suffisante pour promouvoir effectivement les idées et les pratiques des écologies industrielles. Étant donné la prolifération de nouvelles sources de données (telles que les messages, les articles, ou les commentaires) disponibles sur les médias sociaux, les chercheurs pourraient étudier la façon dont le Big Data (les données massives), le forage de données (datamining), le forage textuel (textmining) et le web sémantique pourraient offrir de nouvelles opportunités pour les entreprises tirant parti des médias sociaux.

Ainsi la seconde contribution de cette thèse propose un cadre de mise en œuvre d'une approche hybride qui intègre le web sémantique au web social, ainsi qu'une preuve de concept. Cette approche est basée sur le Web qui est conçue pour être accessible à quiconque. Elle exploite ainsi le potentiel du web sémantique social afin de structurer les contributions individuelles des utilisateurs (par exemple leurs commentaires et réponses à des questions en lignes) afin de favoriser la recherche d'information, et ultimement la collaboration et le partage des connaissances et des informations entre les membres des communautés industrielles en ligne. Cette approche adopte le concept de données ouvertes (Linked Open Data) qui permet le partage et l'échange d'informations avec des systèmes externes qui contiennent d'autres sources d'informations potentiellement pertineentes. Cette caractéristique distingue le cadre proposé des approches existantes, notamment au niveau du processus d'initiation des synergies industrielles, et specifiquement au niveau de l'identification des opportunités de synergies. Des constructions de requêtes ontologiques ont été développées, programmées et testées afin de démontrer la faisabilité de telles fonctions de recherche avancée. L'approche proposée ouvre la voie au développement de la plateforme SSWISI pour la première phase de l'initiation des synergies industrielles.

En d'autres termes, appliquer les technologies du Web sémantique aux réseaux sociaux verts rend l'information sur les réseaux sociaux plus organisée et plus facile à trouver. Le fait qu'il existe déjà des applications sémantiques, par exemple Open Graph, Google Authorship ou Twitter Cards, démontre que le développement d'applications web sémantiques est proche d'aboutir à des applications grand public. L'objectif, dans le cadre du développement des symbioses industrielles est qu'une entreprise soit en mesure de rechercher et de trouver ce dont elle a besoin pour sa matière résiduelle (par exemple des utilisateurs potentiels, des solutions technologiques, ou des fournisseurs de services). En ce qui concerne les perspectives de développement futures, nous suggérons d'étendre et d'améliorer ce travail en validant notre approche sur un plus grand ensemble de données et également d'enrichir notre base de données par des ontologies standards autres que Dbpedia.

Enfin, grâce à la modélisation à base d'agents, nous avons révélé dans une troisième contribution qu'il est possible de prendre en compte des paramètres sociaux comme l'influence sociale, l'intensité des interactions sociales et la structure des réseaux sociaux dans un modèle de simulation de la dynamique des symbioses industrielles auto-organisées. Certes, il reste beaucoup de travail pour calibrer et valider le modèle proposé. Cependant, les résultats préliminaires ont démontré qu'agir sur la dynamique sociale en promouvant notamment le partage des connaissances et en favorisant la confiance peut agir sur le taux de création des synergies industrielles.

On a pu démontrer qu’un niveau plus élevé de dynamique sociale (c'est-à-dire le nombre de nouveaux liens sociaux) augmente de façon significative le pourcentage du nombre de synergies potentielles initiées pour les trois niveaux de synergies potentielles. Ces résultats sont similaires pour toutes les configurations expérimentales. La dynamique sociale influe sur la dynamique auto-organisée de la SI. Il est à noter que le partage des connaissances par le biais des liens sociaux était nécessaire pour atteindre le niveau minimum de connaissances requis en 5 ans en moyenne (Expérience a). Comme on pouvait s'y attendre, on constate qu'un niveau plus faible de connaissances initiales tend à retarder légèrement la création de synergies (il faut plus de temps pour prendre conscience des synergies potentielles). On a pu également modéliser explicitement la confiance en tant qu'attribut d'un lien social entre deux entreprises et l'inclure dans les processus de diffusion des connaissances et de création de synergies. Enfin, après avoir effectué une comparaison entre notre éco-parc industriel virtuel et celui de Kalundborg, on a pu constater que les entreprises sont motivées par un objectif commun de gains en réponse aux opportunités de marchés, tissent des connexions et s’auto-organisent pour s’échanger des ressources ; c’est l’émergence ou le sprouting (Chertow et Ehrenfeld, 2012).

Ceci étant dit, bien que les expériences présentées montrent comment les attributs de SI peuvent émerger les interactions et les comportements des entreprises, ce modèle reste simpliste si on s’appuie sur les nombreuses hypothèses qui ont été faites à son sujet. Les expériences montrent également de quelle manière un tel modèle pourrait être utilisé comme un outil complémentaire pour les études de cas, les enquêtes et d'autres études empiriques, qui fournissent les connaissances nécessaires pour modéliser de manière appropriée. Afin de l'améliorer, il existe de nombreuses possibilités. Par exemple, nous pouvons aborder la stabilité de l'offre, tant en termes de qualité que de quantité, ce qui est nécessaire pour tenir compte explicitement des flux de déchets. En outre, nous pouvons également envisager l'introduction dynamique de nouvelles usines qui peuvent être ajoutées de manière plus ou moins proactive pour créer plus de synergies. Dans cette ligne, nous devrions améliorer la modélisation discrète du temps et du modèle plus précisément, par mois ou même par semaine, ainsi que les flux d'échange, leur prix et coût, ainsi que la matière première et les fluctuations du marché. D'autres facteurs pourraient également être inclus, tels que les contrats d'achat. Enfin, nous devrions aussi étudier les structures de réseau réelles des synergies en SI, et simuler ces structures pour améliorer la précision de notre modèle.

CHAPITRE 8 CONCLUSION ET RECOMMANDATIONS

L'étude de la mise en œuvre et de l'utilisation d'ontologies dans le cadre des symbioses industrielles est encore à un stade préliminaire. Ainsi, le nombre de classes et les relations entre classes décrivant le contexte des symbioses ne suffisent pas à refléter la nature systématique et complexe des synergies. Les ontologies existantes doivent être améliorées continuellement en recueillant des informations connexes. Nous suggérons d'intégrer des concepts et des relations d'autres ontologies standards telles que SIOC (Semantically-Interlinked Online Communities : http://rdfs.org/sioc/spec/), Dublin Core (http://dublincore.org/). Les travaux futurs comprendraient l'utilisation supplémentaire des classes et des propriétés FOAF. Ceux-ci fournissent la sémantique de l'identité à exporter et permettent l'expression des relations et des propriétés de ces individus. Nous visons à étendre notre algorithme pour rechercher plusieurs communautés connectées et nous essayerons également d'extraire des informations d'autres ressources telles que des forums de discussion, des blogs et via des historiques de recherche pour enrichir les connaissances sur les utilisateurs.

D'autres travaux de recherche futurs comprendraient également l'alignement des ontologies, c'est-à-dire l'alignement des concepts et des relations dans deux ontologies différentes qui représentent la même chose, mais qui ne sont pas structurées de la même façon. Par exemple, une entreprise dans Dbpedia est une organisation dans le FOAF, et une éco-organisation dans notre ontologie locale. Le but est de déterminer quand les concepts d'une ontologie sont liés sémantiquement à un concept dans une autre ontologie. Euzenat, et al. (2007) présente une discussion complète de l'alignement et une définition formelle de l'ontologie. Nous pourrions donc faire des ontologies locales qui complètent les données de Dbpedia.

En ce qui concerne le domaine de pratique, les travaux futurs incluent aussi la mise en place d'un serveur de données ouvert lié, c'est-à-dire un serveur Web dédié uniquement au Web sémantique comme Dbpedia, où il serait possible de publier des ontologies, mais aussi pour rechercher des informations d'autres ontologies standards. Une plate-forme de réseau social pourrait ainsi utiliser ces données vers le serveur Linked Open Data.

Enfin, il est à noter que le choix approprié des tags est un critère qui a influencé la qualité des informations qui se sont produites. S'il y a trop de tags, la requête risque d'engendrer très peu de résultats. S'il n'y a pas assez de tags, la requête risque d'aboutir dans un délai trop long et avec une trop grande quantité d'informations. Il n'existe pas de règles systématiques concernant le choix des tags et leur agencement logique dans une requête. Seule une étude de la source de données et l'exécution de plusieurs essais renforcés par un suivi rigoureux des traces d'exécution, peuvent permettre de converger vers une performance attendue.

Enfin, il est à noter qu'avant d'entreprendre d'exploiter une méthode de validation quelconque pour une ontologie, il importe de bien comprendre l'usage que prendra l'ontologie dans la solution envisagée. D'ordre général, une ontologie est exploitée pour générer de nouvelles inférences (c.-à-d. : de nouveaux triplets). L'instanciation de triplets peut être produite par deux mécanismes : soit par l'utilisation de requêtes de type SPARQL, soit par l'utilisation de la déduction logique. Parfois même par hybridation des deux. Dans le présent projet, il a été choisi d'exploiter l'ontologie par des requêtes SPARQL. Ce choix s'explique par la nature même du problème à traiter (recherche d'informations, fouille sur le web, etc.). Dans ce contexte, il est à noter que l'utilisation de la logique n'est pas très utile et les défaillances structurelles (cohésion, complétude, cohérence) de l'ontologie ont peu de conséquences sur les performances de système. Ici, nous visons surtout à exploiter le volet interopérabilité qui caractérise les ontologies du web sémantique.

En revanche, l'exploitation de la logique sera utile pour la confection de systèmes à base de connaissances tels que les systèmes experts, les systèmes d'aide à la prise de décisions, etc. Dans cette perspective, en fonction de la logique et de la qualité de déductions, /je jouerais un rôle primordial dans la viabilité de la solution. Des outils tels que Pellet OWLIM et autres moteurs d'inférence peuvent assister le chercheur dans la validation de la structure de l'ontologie.

En ce qui concerne l'ontologie Eco, il est prématuré d'exprimer une opinion précise sur la validité de l'ontologie. Bien sûr, dans son état actuel, l'ontologie réalise ce qu'elle a à faire et les cas de tests, bien qu'ils ne soient pas très élaborés, démontrent que l'ontologie produit des résultats valides.

En revanche, à la lumière des énoncés de départ, il apparaît que les usages attendus du système gagneraient à être plus définis. Par exemple, il a été spécifié que la classe Company soit de type foaf: Organization. Or, à aucun moment cette caractéristique n'est exploitée par les cas d’utilisation. Il s’agit là d’un type d’erreur de complétude qui arrive lorsque les cas d’usages sont mal ou peu définis.

En ce qui concerne les perspectives futures de la contribution portant sur la modélisation à base d’agent, il est important de souligner quelques points considérés comme étant les limites du projet de recherche. Premièrement, le manque quasi général de données sur le développement des symbioses industrielles et sur leurs conditions détaillées de développement limite très fortement la calibration et la validation des modèles à base d’agents. Il est donc nécessaire lors du développement de nouveau modèle de concevoir et mettre en œuvre des méthodes de collectes d’informations. Cependant, même s’il était possible d’avoir des informations détaillées, la MABA restera en grande partie limitée à l’étude de grandes tendances, ou à la prévision d’impact relativement agrégé de certains facteurs.

Le développement de nouveaux modèles plus précis est donc un travail continu, à l’image du processus de développement de notre modèle qui est le résultat d'un processus de modélisation itérative. À notre connaissance, c'est l'un des premiers modèles à base d’agents dédié à l’étude de l’évolution de symbioses industrielles, et certainement le modèle implémenté et testé le plus détaillé à ce jour au niveau des aspects sociaux.

Les travaux futurs spécifiques à notre modèle nécessitent ainsi de pousser plus loin la validation du modèle à partir de données empiriques. La simulation présentée n’est ainsi qu’une première étape de recherche qui devrait être poursuivie avec des analyses quantitatives plus approfondies. Il faut de plus développer encore le modèle. Par exemple, dans notre modèle, un agent ne peut créer qu’une seule synergie. Il est évident que si les entreprises avaient une grande diversité d'intrants et de produits, il y aurait de nombreuses nouvelles occasions d'affaires fondées sur la réutilisation des sous-produits. Le modèle devrait aussi modéliser explicitement les flux de matières et offrir des analyses financières plus détaillées, et cela sur des territoires plus grands, voire nationaux.

Par ailleurs, nous pensons que les sciences sociales et de l’administration pourraient jouer un rôle prépondérant dans la modélisation des symbioses industrielle (c’est-à-dire tenir compte des interactions complexes, des motivations et des dynamiques qui se produisent au sein et entre les organisations) pour contribuer à des modèles plus détaillés des symbioses industrielles. Cet aspect a été récemment abordé par Walls et Paquin (2015).

BIBLIOGRAPHIE

Albino, V., Carbonara, N., & Giannoccaro, I. (2006). Innovation in industrial districts: An agent-based simulation model. International Journal of Production Economics, 104(1), 30-45.

Albino, V., Fraccascia, L., & Giannoccaro, I. (2016). Exploring the role of contracts to support the emergence of self-organized industrial symbiosis networks: an agent-based simulation study. Journal of Cleaner Production, 112, 4353-4366.

Anon., (2000). *Resource Description Framework (RDF) Schema Specification 1.0 - W3C Candidate Recommendation.* s.l.:s.n.

Anon., (2004). *OWL Web Ontology Language Reference - W3C Recommendation.* s.l.:s.n.

Anon., (2012). *OWL 2 Web Ontology Language Document Overview - W3C Recommendation.* s.l.:s.n.

Anon., (2013). *SPARQL 1.1 Query Language - W3C Recommendation.* s.l.:s.n.

Anon., (2014). *The RDF Data Cube Vocabulary - W3C Recommendation.* s.l.:s.n.

Anon., n.d. *DBpedia.* s.l.:s.n.

Anon., n.d. *schema.org.* s.l.:s.n.

Ashton, W. (2008). Understanding the organization of industrial ecosystems. Journal of Industrial Ecology, 12(1), 34-51.

Ashton, W. S. 2009. The Structure, Function, and Evolution of a Regional Industrial Ecosystem. Journal of Industrial Ecology 13 (2), 228-246.

Ashton, W. S., & Bain, A. C. (2012). Assessing the “Short Mental Distance” in Eco-Industrial Networks. Journal of Industrial Ecology, 16(1), 70-82.

Auer, S., Lehmann, J. & Ngomo, A.-C. N., (2011). Introduction to linked data and its lifecycle on the web. In: *Reasoning Web. Semantic Technologies for the Web of Data.* s.l.:Springer, pp. 1-75.

Ayres, R. U. (1988). Self-organization in biology and economics.

Axelrod, R. (1997). Advancing the art of simulation in the social sciences. In Simulating social phenomena (pp. 21-40). Springer Berlin Heidelberg.

Axelrod, R., & Tesfatsion, L. (2006). Appendix AA guide for newcomers to agent-based modeling in the social sciences. *Handbook of computational economics*, *2*, 1647-1659.

Axtell, R. L., Andrews, C. J., & Small, M. J. (2001). Agent-based modeling and industrial ecology. Journal of Industrial Ecology, 5(4), 10-14.

Balbi, S., & Giupponi, C. (2009). Reviewing agent-based modelling of socio-ecosystems: a methodology for the analysis of climate change adaptation and sustainability. University Ca'Foscari of Venice, Dept. of Economics Research Paper Series, (15_09).

Barnes, J.A., (1954). Class and Committees in a Norwegian Island Parish, Human Relations, 7, pp. 39–58.

Barnes, D. J., & Chu, D. (2010). Agent-based modeling. In Introduction to Modeling for Biosciences (pp. 15-77). Springer London.

Baas, M., De Dreu, C. K., & Nijstad, B. A. (2008). A meta-analysis of 25 years of mood-creativity research: Hedonic tone, activation, or regulatory focus?. Psychological bulletin, 134(6), 779.

Barabási, A. L., & Albert, R. (1999). Emergence of scaling in random networks. science, 286(5439), 509-512.

Beers, D., Bossilkov, A., Corder, G., & Berkel, R. (2007). Industrial symbiosis in the Australian minerals industry: the cases of Kwinana and Gladstone. Journal of industrial ecology, 11(1), 55-72.

Berners-Lee, T., Hendler, J., Lassila, O. & others, (2001). The semantic web. *Scientific american*, 284(5), pp. 28-37.

Bichraoui, N., Guillaume, B., & Halog, A. (2013). Agent-Based modelling simulation for the development of an industrial symbiosis-Preliminary results. Procedia Environmental Sciences, 17, 195-204.

Bizer, C., (2009). The emerging web of linked data. *IEEE intelligent systems*, 24(5), pp. 87-92.

Bizer, C., Heath, T. & Berners-Lee, T., (2009). Linked data-the story so far. *International Journal on Semantic Web and Information Systems*, 5(3), pp. 1-22.

Bizer, C. et al., (2009). DBpedia-A crystallization point for the Web of Data. *Web Semantics: science, services and agents on the world wide web,* 7(3), pp. 154-165.

Blumauer, A., & Pellegrini, T. (2009). Social Semantic Web. Web 2.0-was nun.

Boisot, M. and Canals, A. (2004). Data, Information, and Knowledge: Have we got it right, Journal of Evolutionary Economics, v. 14, pp. 43–67.

Boix, M., Montastruc, L., Azzaro-Pantel, C., & Domenech, S. (2015). Optimization methods applied to the design of eco-industrial parks: a literature review. Journal of Cleaner Production, 87, 303-317.

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences, 99(suppl 3), 7280-7287.

Boons, F. A. A., & Baas, L. W. (1997). Types of industrial ecology: the problem of coordination. Journal of Cleaner Production, 5(1), 79-86.

Boons, F., Spekkink, W., & Mouzakitis, Y. (2011). The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. Journal of Cleaner Production, 19(9), 905-911.

Boons, F., Spekkink, W., & Jiao, W. (2014). A process perspective on industrial symbiosis. Journal of Industrial Ecology, 18(3), 341-355.

Boyd, D., (2007). Why Youth (Heart) social networking Sites: The Role of Networked Publics in Teenage Social Life, in Youth, Identity and Social Media, D. Buckingham (Ed.), Cambridge MA: MIT Press, pp. 119–142.

Boschma, R. (2005). Proximity and innovation: a critical assessment. Regional studies, 39(1), 61-74.

Boyer, C. (2011). Social media for healthcare makes sense. Frontiers of Health Services Management, 28(2), 35□40.

Breslin, J., Passant, A., & Decker, S. (2009). The social semantic web. Springer Science & Business Media.

Breslin, J. G., Passant, A., & Vrandečić, D. (2011). Social semantic web. In Handbook of Semantic Web Technologies (pp. 467-506). Springer Berlin Heidelberg.

Brickley, D. & Miller, L., (2010). *FOAF Vocabulary Specification 0.98. Namespace Document, 9 August 2010-Marco Polo Edition.* s.l.:s.n.

Brooks, S. S. Brooks, X. Wang, S. Sarker, (2012). Unpacking green IS: a review of the existing literature and directions for the future. J. vom Brocke (Ed.), et al., Green Business Process Management, Springer-Verlag, Berlin, Heidelberg, Germany), pp. 15–37.

Burström, F., & Korhonen, J. (2001). Municipalities and industrial ecology: reconsidering municipal environmental management. Sustainable Development, 9(1), 36-46.

Butt, A. S. & Khan, S., (2014). Scalability and Performance Evaluation of Semantic Web Databases. *Arabian Journal for Science and Engineering*, 39(3), pp. 1805-1823.

Cao, K., Feng, X., & Wan, H. (2009). Applying agent-based modeling to the evolution of eco-industrial systems. Ecological Economics, 68(11), 2868-2876.

Cartier, M., & Forgues, B. (2006). Intérêt de la simulation pour les sciences de gestion. Revue française de gestion, (6), 125-137.

Cardinal Group, (2013). What is Eco-Industrial Networking? [Online]. http://www.cardinalgroup.ca/cein/whatsein.html (Date accessed 23 October 2013).

Cavico, F. J., Mujtaba, B. G., Muffler, S. C., and Samuel, M. (2013). social media and employment-at-will: Tort law and practical considerations for employees, managers and organizations. New Mass and Mass Communication, 11, 25–41.

Cecelja, F. et al., (2015). e-Symbiosis: technology-enabled support for Industrial Symbiosis targeting Small and Medium Enterprises and innovation. *Journal of Cleaner Production,* Volume 98, pp. 336-352.

Chertow, M. R., (2000). Industrial symbiosis: Literature and taxonomy. Annual Review of Energy and the Environment 25: 313–337.

Chertow, M., Lombardi, R., (2005). Quantifying economic and environmental benefits of co-located firms. Environmental Science and Technology. 39(17): 6535–6541.

Chertow, M., (2007). “Uncovering” industrial symbiosis. Journal of Industrial Ecology. 11(1): 11–30.

Chertow, M., Ashton, W.S, Espinosa J.C., (2008) Industrial symbiosis in Puerto Rico: environmentally related agglomeration economies. Regional Studies; 42 (10): 1299–1312.

Chertow, M., & Ehrenfeld, J. (2012). Organizing Self-Organizing Systems. Journal of Industrial Ecology, 16(1), 13-27.

Chertow, M., & Park, J. (2016). Scholarship and Practice in Industrial Symbiosis: 1989–2014. In Taking Stock of Industrial Ecology (pp. 87-116). Springer International Publishing.

Cimren, E., Fiksel, J., Posner, M. E., and Sikdar, K. (2011). Material Flow Optimization in By-product Synergy Networks. Journal of Industrial Ecology. 15(2), 315□332.

Cohen-Rosenthal, E. (1996). Top Myths about Eco-Industrial Parks. Center for the Environment at Cornell University.

Cooper, R. G., (2001). The New Product Process: The Stage-Gate Game Plan, in Winning at New Products: Accelerating the Process from Idea to Launch, 3rd ed. Cambridge, MA: Perseus Publishing, pp. 113□153.

Costa, I., & Ferrão, P. (2010). A case study of industrial symbiosis development using a middle-out approach. Journal of Cleaner Production, 18(10), 984-992.

Côté, R.P., Cohen-Rosenthal, E., (1998). Designing eco-industrial parks: a synthesis of some experiences. Journal of Cleaner Production. 6, pp. 181□188.

Crooks, A. T., & Heppenstall, A. J. (2012). Introduction to agent-based modelling. In Agent-based models of geographical systems (pp. 85-105). Springer Netherlands.

Crooks, A. T., & Hailegiorgis, A. B. (2014). An agent-based modeling approach applied to the spread of cholera. Environmental Modelling & Software, 62, 164-177.

Davies, T. & Edwards, D., (2012). Emerging implications of open and linked data for knowledge sharing in development. *IDS Bulletin*, 43(5), pp. 117-127.

Davis, C., Nikolic, I. & Dijkema, G. P., (2010). Industrial Ecology 2.0. *Journal of Industrial Ecology*, 14(5), pp. 707-726.

Davis, C., (2012). Making Sense of Open Data From Raw Data to Actionable Insight, PhD thesis, Delft University of Technology. Next Generation Infrastructure Foundation.

Davis, C. B., Chmieliauskas, A., & Nikolic, G. P. J. (2013). Enipedia. Energy & Industry Group. Faculty of Technology. Policy and Management, TU, Delft, The Netherlands, Retrieved from http://enipedia. tudelft. nl.

Desrochers, P., (2004). Industrial symbiosis: a case of market coordination. Journal of Cleaner Production. 12(8-10), pp. 1099–1110.

Dijkema, G. P., & Basson, L. (2009). Complexity and industrial ecology. Journal of Industrial Ecology, 13(2), 157-164.

Ding, L., Kolari, P., Ding, Z. & Avancha, S., (2007). Using Ontologies in the Semantic Web: A Survey. In: R. Sharman, R. Kishore & R. Ramesh, eds. *Ontologies: A Handbook of Principles, Concepts and Applications in Information Systems.* s.l.:Springer US, pp. 79-113.

Domenech, T., & Davies, M. (2009). The social aspects of industrial symbiosis: the application of social network analysis to industrial symbiosis networks. Progress in Industrial Ecology, an International Journal, 6(1), 68-99.

Doménech, T., & Davies, M. (2011). The role of embeddedness in industrial symbiosis networks: Phases in the evolution of industrial symbiosis networks. Business Strategy and the Environment, 20(5), 281-296.

Dong, L., Zhang, H., Fujita, T., Ohnishi, S., Li, H. Q., Fujii, M., & Dong, H. J. (2013). Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki’s experi- ence and practice in Liuzhou and Jinan. Journal of Cleaner Production, 59, 226–238

Dougherty, L., (1997). Denmark shows the way. Dollars and Sense. Available at: http://www.dollarsandsense.org/archives/1997/0597dougherty.html.

Duflou, J. R., Sutherland, J. W., Dornfeld, D., Herrmann, C., Jeswiet, J., Kara, S., Hauschild, M., and Kellens, K., (2012). Towards Energy and Resource Efficient Manufacturing: A Processes and Systems Approach. CIRP Ann., 61(2), pp. 587–609.

Egan, J. (2011). Relationship Marketing Exploring Relational Strategies in Marketing (Vol. Fourth Edition): Prentice Hall.

Ehrenfeld, J. R. (2007). Would industrial ecology exist without sustainability in the background?. Journal of Industrial Ecology, 11(1), 73-84.

Ellison, N., Steinfield, C., and Lampe, C. (2007). The benefits of Facebook “friends”: Exploring the relationship between college students’ use of online social networks and social capital. Journal of Computer-Mediated Communication, 12(3), article 1. Retrieved July 30, 2014 from http://onlinelibrary.wiley.com/doi/10.1111/j.1083-6101.2007.00367.x/abstract.

Elabras Veiga, L. B., & Magrini, A. (2009). Eco-industrial park development in Rio de Janeiro, Brazil: A tool for sustainable development. Journal of Cleaner Production, 17(7), 653–661.

Enders, A., Hungenberg, H., Denker, H. P., and Mauch, S. (2008). The long tail of social networking: Revenue models of social networking sites. European Management Journal, 26(3), 199□211.

Euzenat, J., & Shvaiko, P. (2007). Ontology matching (Vol. 18). Heidelberg: Springer.

Farid, H., Khan, S. & Javed, M. Y., (2016). DSont: DSpace to ontology transformation. *Journal of Information Science,* 42(2), pp. 179-199.

Feisal, A., (2013). Assessment of industrial by-product synergies from process engineering and sustainability principles. Progress in Industrial Ecology, an International Journal, Vol.8, No. 3

Fernandez-Mena, H., Nesme, T., & Pellerin, S. (2016). Towards an Agro-Industrial Ecology: A review of nutrient flow modelling and assessment tools in agro-food systems at the local scale. Science of the Total Environment, 543, 467-479.

Fischer, E. and Reuber, A. R. (2011). Social interaction via new social media: (How) can interactions on Twitter affect effectual thinking and behavior? Journal of Business Venturing, 26 pp. 1□18.

Frosch, R.A., Gallopoulos, N.E. (1989). Strategies for Manufacturing. Scientific American, 261 (3), pp. 144–152.

Gertler, M. S. (1995) “Being there”: proximity, organization, and culture in the development and adoption of advanced manufacturing technologies, Economic Geography, 71(1), pp. 1–26.

Geng, Y., Doberstein, B., (2008). Developing the circular economy in China: challenges and opportunities for achieving 'leapfrog development.' International Journal of Sustainable Development and World Ecology. 15(3), pp. 1–9.

Ghali, M. R., Frayret, J.-M. & Robert, J.-M., (2016). Green social networking: concept and potential applications to initiate industrial synergies. *Journal of Cleaner Production* , Volume 115, pp. 23-35.

Gibbs, D., (2003). Trust and networking in inter-firm relations: the case of eco-industrial development. Local Economy, 18, pp. 222–36.

Gibbs, D., Deutz, P., & Proctor, A. (2005). Industrial ecology and eco-industrial development: A potential paradigm for local and regional development?. Regional Studies, 39(2), 171-183.

Gibbs, D., & Deutz, P. (2007). Reflections on implementing industrial ecology through eco-industrial park development. Journal of Cleaner Production, 15(17), 1683-1695.

Gilbert, N., & Troitzsch, K. (2005). Simulation for the social scientist. McGraw-Hill Education (UK).

Golbeck, J. & Rothstein, M., (2008). *Linking Social Networks on the Web with FOAF: A Semantic Web Case Study*.. s.l., s.n., pp. 1138-1143.

Golev, A., & Corder, G. D. (2012). Developing a classification system for regional resource synergies. Minerals Engineering, 29, 58-64.

Granovetter, M.S., (1985). Economic action and social structure: the problem of embeddedness American Journal of Sociology, 91 (1985), pp. 481–510.

Grant, G. B., Seager, T. P., Massard, G. & Nies, L., (2010). Information and communication technology for industrial symbiosis. *Journal of Industrial Ecology,* 14(5), pp. 740-753.

Gregson, N., Crang, M., Ahamed, F. U., Akter, N., Ferdous, R., Foisal, S., & Hudson, R. (2012). Territorial agglomeration and industrial symbiosis: Sitakunda-Bhatiary, Bangladesh, as a secondary processing complex. Economic Geography, 88(1), 37–58.

Gruber, T. (2007). Ontology of folksonomy: A mash-up of apples and oranges. International Journal on Semantic Web and Information Systems (IJSWIS), 3(1), 1-11

Gruber, T., (2008). Collective knowledge systems: Where the Social Web meets the Semantic Web. *Web Semantics: Science, Services and Agents on the World Wide Web,* 6(1), pp. 4-13.

Gruber, T. R., (1995). Toward principles for the design of ontologies used for knowledge sharing?. *International journal of human-computer studies,* 43(5), pp. 907-928.

Halpin, H., & Tuffield, M. (2010). Social Web XG Wiki. World Wide Web Consortium (W3C).

Hardy, C. and Graedel, T. E. 2002. Industrial Ecosystems as Food Webs. Journal of In- dustrial Ecology 6 (1): 29–38.

Hatefipour, S. (2012). Facilitation of industrial symbiosis development in a Swedish region.

Heath, T. & Bizer, C., 2011. *Linked Data: Evolving the Web into a Global Data Space.* s.l.:Morgan \& Claypool Publishers.

Heeres, R.R., Vermeulen, W.J.V., de Walle, F.B., (2004). Eco-industrial park initiatives in the USA and the Netherlands: first lessons. Journal of Cleaner Production, 12(8–10), pp. 985–995.

Hertwich, E. 2007. ISIE—An offline community? ISIE News 7(2): 9.

Hewes, A. K., & Lyons, D. I. (2008). The humanistic side of eco-industrial parks: champions and the role of trust. Regional Studies, 42(10), 1329-1342.

Horrocks, I., (2008). Ontologies and the semantic web. *Communications of the ACM,* 51(12), pp. 58-67.

Howard-Grenville, J., & Paquin, R. (2009). Organizational dynamics in industrial ecosystems: Insights from organizational theory. Changing Stocks, Flows and Behaviors in Industrial Ecosystems, Edward Elgar Publishing, Northampton, MA, 122-139.

Isenmann, R., Chernykh, K. (2009): The role of ICT in industrial symbiosis projects – Environmental ICT applications for eco-industrial development, Proceedings of the 23rd International Conference on Informatics for Environmental Protection, Environmental Informatics and Industrial Environmental Protection: Concepts, Methods and Tools. Vol.2: Workshops, pp. 231□242. Conference Held in September 2009 on Berlin, Germany.

Jacobsen, N. B., (2006). Industrial Symbiosis in Kalundborg, Denmark: A Quantitative Assessment of Economic and Environmental Aspects. Journal of Industrial Ecology, 10(1-2), 239□255.

Jennings, N. R., Sycara, K., & Wooldridge, M. (1998). A roadmap of agent research and development. Autonomous agents and multi-agent systems, 1(1), 7-38.

Jensen, P.D., Basson, L., Hellawell, E.E., Bailey, M.R., and Leach, M., (2011). Quantifying ‘geographic proximity’: Experiences from the United Kingdom’s National Industrial Symbiosis Programme. Resources Conservation and Recycling. 55(7), pp. 703712.

Jeremić, Z., Jovanović, J., & Gašević, D. (2011). An environment for project-based collaborative learning of software design patterns. International Journal on Engineering Education, 27(1), 41-51.

Jeremić, Z., Jovanović, J., & Gašević, D. (2013). Personal learning environments on the social semantic web. Semantic Web, 4(1), 23-51.

Jian, L., & Zengqiang, W. (2009, October). The MAS-based information model of Eco-industrial system. In Industrial Engineering and Engineering Management, 2009. IE&EM'09. 16th International Conference on (pp. 2026-2029). IEEE.

Jovanovic, J., Gasevic, D., & Devedzic, V. (2009). E-learning and the social semantic web. The Future of Learning, 245.

Kaplan, A. M., and Haenlein, M. (2010). Users of the world, unite! The challenges and opportunities of Social Media. Business Horizons, 53(1), 59–68.

Karim, N. et al., (2015). Storage schema and ontology-independent SPARQL to HiveQL translation. *The Journal of Supercomputing*, 71(7), pp. 2694-2719.

Kay, J. J. (2004). On complexity theory, exergy and industrial ecology. Construction Ecology: Nature as the Basis for Green Buildings; Kibert, C., Sendzimir, J., Guy, B., Eds, 72-107.

Kelly, R. A., Jakeman, A. J., Barreteau, O., Borsuk, M. E., ElSawah, S., Hamilton, S. H., ... & van Delden, H. (2013). Selecting among five common modelling approaches for integrated environmental assessment and management. Environmental Modelling & Software, 47, 159-181.

Khan, M.Y. (1999). Theory & Problems in Financial Management. Boston: McGraw Hill Higher Education.

Kietzmann, J.H., Hermkens, K., McCarthy, I.P., Silvestre, B.S. (2011). Social Media? Get Serious! Understanding the Functional Building Blocks of Social Media. Business Horizons 54(1), pp. 241□251.

Kim, H., Ryu, J. H., & Lee, I. B. (2012). Development of an agent-based modeling methodology for an industrial byproduct exchange network design. Industrial & Engineering Chemistry Research, 51(33), 10860-10868.

Knoben, J., & Oerlemans, L. A. (2006). Proximity and inter-organizational collaboration: A literature review. International Journal of Management Reviews, 8(2), 71-89.

Korhonen, J. and Snäkin, J. P. 2005. Analysing the Evolution of Industrial Ecosystems: Concepts and Application. Ecological Economics 52 (2): 169–186.

Kraines, S., & Wallace, D. (2006). Applying Agent-based Simulation in Industrial Ecology. Journal of Industrial Ecology, 10(1-2), 15-18.

Lambert, A. J. D., & Boons, F. A. (2002). Eco-industrial parks: stimulating sustainable development in mixed industrial parks. Technovation, 22(8), 471-484.

Lehmann, J. et al., (2015). DBpedia--a large-scale, multilingual knowledge base extracted from Wikipedia. *Semantic Web,* 6(2), pp. 167-195.

Li, Y. & Shi, L., (2015). The resilience of interdependent industrial symbiosis networks: A case of Yixing Economic and Technological Development Zone. *Journal of Industrial Ecology*, 19(2), pp. 264-273.

Lombardi, R., Laybourn, P., (2012). Redefining Industrial Symbiosis. Journal of Industrial Ecology, 16(1), pp. 28–37.

Lowe, E. A., and Evans, L. K. 1995. Industrial Ecology and Industrial Ecosystems. Journal of Cleaner Production 3 (1-2): 47–53.

Lowe, E. A. (1997). Creating by-product resource exchanges: strategies for eco-industrial parks. Journal of cleaner production, 5(1), 57-65.

Lyons, D. I. (2007). A spatial analysis of loop closing among recycling, remanufacturing, and waste treatment firms in Texas. Journal of Industrial Ecology, 11(1), 43-54.

Macal, C. M., & North, M. J. (2008, December). Agent-based modeling and simulation: ABMS examples. In Proceedings of the 40th Conference on Winter Simulation (pp. 101-112). Winter Simulation Conference.

Maillé, M. & Frayret, J.-M., (2016). Industrial Waste Reuse and By-product Synergy Optimization. *Journal of Industrial Ecology,* pp. n/a--n/a.

McGloughlin, C. and Lee, M.J.W. (2010). Personalised and self-regulated learning in the Web 2.0 era: International exemplars of innovative pedagogy using social software. Australasian Journal of Educational Technology, 26 (1), pp. 28–43.

Meneghetti, A., Nardin, G., (2012). Enabling industrial symbiosis by a facilities management optimization approach. Journal of Cleaner Production, 35, pp. 263–273.

Mika, P., & Greaves, M. (2012). Editorial: Semantic web & web 2.0. Web Semantics: Science, Services and Agents on the World Wide Web, 6(1).

Mikroyannidis, A., (2007). Toward a social semantic web. *Computer,* 40(11), pp. 113-115.

Miles, R.E., Snow C.C., Fjeldstad O.D., Miles, G., Lettl, C., (2010) Designing organizations to meet 21st-century opportunities and challenges. Organizational Dynamics, 39(2), pp. 93□103.

Miller, J. H., & Page, S. E. (2009). Complex adaptive systems: An introduction to computational models of social life. Princeton university press.

Mirata, M., (2004). Experiences from early stages of a national industrial symbiosis programme in the UK: determinants and coordination challenges. Journal of Cleaner Production, 12(8-10), pp. 967□983.

Mirata, M., Emtairah, T., (2005). Industrial symbiosis networks and the contribution to environmental innovation: the case of the Landskrona industrial symbiosis programme. Journal of Cleaner Production 13(10-11), pp. 993□1002.

Musial, K. & Kazienko, P., (2013). Social networks on the internet. *World Wide Web,* 16(1), pp. 31-72.

Nonaka, I., Toyama, R., Byosiere, Ph. (2001), “A theory of organizational knowledge creation: understanding the dynamic process of creating knowledge,” in Dierkes, M., Antal, A.B., Child, J., Nonaka, I. (eds.), Handbook of organizational learning and knowledge, pp. 487□491, Oxford University Press, Oxford.

Nooij, S., (2014). *An ontology of Industrial Symbiosis: The design of a support tool for collaborative Industrial Symbiosis research with as test cases from Tianjin Economic Development Area and Kalundborg,* s.l.: s.n.

Nooteboom, B., & Gilsing, V. A. (2004). Density and strength of ties in innovation networks: a competence and governance view.

Nov, O. and Naaman, M. and Ye, C.(2009). "Analysis of participation in an online photo-sharing community: a multidimensional perspective." Journal of the American Society for Information Sciences and Technology, 61(3):555□66.

Nunes Amaral, L. A., Scala, A., Barthelemy, M., & Stanley, H. E. (2000). Classes of behavior of small-world networks. arXiv preprint cond-mat/0001458.

Ohnishi, S., Fujita, T., Chen, X., & Fujii, M. (2012). Econometric analysis of the performance of recycling projects in Japanese Eco-Towns. Journal of Cleaner Production, 33, 217-225.

Paquin, R.L., Howard-Grenville, J., (2012). The evolution of facilitated industrial symbiosis. Journal of Industrial Ecology, 16(1), pp. 83□93.

Park, H. S., Rene, E. R., Choi, S. M., & Chiu, A. S. (2008). Strategies for sustainable development of industrial park in Ulsan, South Korea—from spontaneous evolution to systematic expansion of industrial symbiosis. Journal of Environmental Management, 87(1), 1-13.

Passant, A., Laublet, P., Breslin, J. G. & Decker, S., (2010). Enhancing enterprise 2.0 ecosystems using semantic web and linked data technologies: The SemSLATES approach. In: *Linking Enterprise Data.* s.l.:Springer, pp. 79-102.

Pillmann, W., Geiger, W., Voigt, K., (2006). Survey of environmental informatics in Europe. Environmental Modeling and Software 21(11), pp. 1519□1527.

Povh, J. (2015). *Applied modelling and computing in social science*. Peter Lang.

Projet COMETHE. L'Écologie industrielle. In Eutech SSII et Home Sweet Com. Conception d'Outils METhodologie et d'evaluation pour l'Écologie industrielle, [Online].http://www.comethe.org/index.php?option=com_contentandview=articleandid=49andItemid=85 (Date accessed 10 August 2013).

Raafat, T., Trokanas, N., Cecelja, F. & Bimi, X., (2013). An ontological approach towards enabling processing technologies participation in industrial symbiosis. *Computers \& Chemical Engineering* , Volume 59, pp. 33-46.

Roberts, B.H., (2004). The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study. Journal of Cleaner Production 12, 997–1010.

Renner, G. T. (1947). Geography of Industrial Localization. Economic Geography 23(3): 167-189.

Romero, E., & Ruiz, M. C. (2014). Proposal of an agent-based analytical model to convert industrial areas in industrial eco-systems. Science of the Total Environment, 468, 394-405.

Sakr, D., Baas, L., El-Haggar, S., Huisingh, D. (2011). Critical success and limiting factors for eco-industrial parks: global trends and Egyptian context. Journal of Cleaner Production, 19(11), pp. 1158□1169.

Sapkota, B., Ludwig, L., Zhou, X. & Breslin, J. G., (2015). Sifo-peers: A social foaf based peer-to-peer network. *Communications of the IIMA,* 5(4), p. 11.

Sauvageau, G., & Frayret, J. M. (2013). Agent-Based Simulation of Waste Paper Procurement and Recycled Pulp Production.

Sharp, J., (2011). Brand awareness and engagement: a case study in healthcare social media. Frontiers of Health Services Management, 28 (2), pp. 29–33.

Shi, H., Chertow, M., & Song, Y. (2010). Developing country experience with eco-industrial parks: a case study of the Tianjin Economic-Technological Development Area in China. Journal of Cleaner Production, 18(3), 191-199.

Shih, C. (2009). , The Facebook Era: Tapping Online social networks to Build Better Products, Reach New Audiences, and Sell More Stuff. Boston, MA: Prentice Hall.

Simov, K. & Kiryakov, A., (2015). *Accessing Linked Open Data via A Common Ontology.* s.l., s.n., p. 33.

Smith, Michael C. (Spring, 2012). Social media Update. The Advocate, Vol. 58, pp. 1□12.

Spekkink, W. (2015). Building capacity for sustainable regional industrial systems: an event sequence analysis of developments in the Sloe Area and Canal Zone. Journal of Cleaner Production, 98, 133-144.

Spekkink, W. (2016). Industrial Symbiosis as a Social Process.

Sterr, T., & Ott, T. (2004). The industrial region as a promising unit for eco-industrial development—reflections, practical experience and establishment of innovative instruments to support industrial ecology. Journal of Cleaner Production, 12(8), 947-965.

Taddeo, R., Simboli, A., & Morgante, A. (2012). Implementing eco-industrial parks in existing clusters. Findings from a historical Italian chemical site. Journal of Cleaner Production, 33, 22-29.

Torniai, C., Jovanovic, J., Gaševic, D., Bateman, S., & Hatala, M. (2008, July). E-learning meets the social semantic web. In 2008 Eighth IEEE International Conference on Advanced Learning Technologies (pp. 389-393). IEEE.

Trokanas, N., Raafat, T., Cecelja, F., & Kokossis, A. (2013). OFIS–ontological frame-work for industrial symbiosis. Computer aided chemical engineering, 32.

Trokanas, N., Cecelja, F. & Raafat, T., (2014). Semantic input/output matching for waste processing in industrial symbiosis. *Computers \& Chemical Engineering*, Volume 66, pp. 259-268.

Trokanas, N., Cecelja, F., & Raafat, T. (2015). Semantic approach for pre-assessment of environmental indicators in Industrial Symbiosis. Journal of Cleaner Production, 96, 349-361.

Tsai, W. (1998). Strategic linking capability in intraorganizational networks. Academy of Management Proceedings, Academy of Management: San Diego, CA.

Uzzi, B. (1997). Social structure and competition in interfirm networks: The paradox of embeddedness. Administrative science quarterly, 35-67.

Van Beers, D., Corder, G., Bossilkov, A., van Berkel, R., (2007). Industrial symbiosis in the Australian minerals industry: the cases of Kwinana and Gladstone. J. Ind. Ecol. 11 (1), pp. 55□72.

Van Berkel, R., Majer, J. and Stehlik, D. (2007). Regional Resource Synergies for Sustainable Development in Heavy Industrial Areas: An Overview of Opportunities and Experiences. Perth: Curtain University of Technology – Centre of Excellence in Cleaner Production.

Van Berkel, R. (2009). Comparability of industrial symbioses. Journal of Industrial Ecology, 13(4), 483-486.

Van Berkel, R., Fujita, T., Hashimoto, S. and Geng, Y. (2009). Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997-2006. Journal of Environmental Management 90 (3): 1544-1556.

Van Leeuwen, M. G., Vermeulen, W. J., & Glasbergen, P. (2003). Planning eco-industrial parks: an analysis of Dutch planning methods. Business Strategy and the Environment, 12(3), 147-162.

Velenturf, A. P., & Jensen, P. D. (2015). Promoting industrial symbiosis: using the concept of proximity to explore social network development. Journal of Industrial Ecology.

Walker, G., Kogut, B., & Shan, W. (1997). Social capital, structural holes and the formation of an industry network. Organization science, 8(2), 109-125.

Walls, J. L. & Paquin, R. L., (2015). Organizational Perspectives of Industrial Symbiosis A Review and Synthesis. *Organization \& Environment*, 28(1), pp. 32-53.

Watson, R. T., Boudreau, M.-C., and Chen, A. J. W. (2010). Information Systems and Environmentally Sustainable Development: Energy Informatics and New Directions for the IS Community, MIS Quarterly (34:1), pp. 23□38.

Wheeler, S., Yeomans, P. and Wheeler, D. (2008). The good, the bad and the wiki: Evaluating student generated content as a collaborative learning tool. British Journal of Educational Technology, 39 (6), 987□995.

Wilson, M., (2008). The comparison of online social networks in terms of structure and evolution. (Doctoral dissertation, University of Maryland, 2008). ProQuest Dissertation and Theses, 166, 3316158.

Wooldridge, M., & Jennings, N. R. (1995). Intelligent agents: Theory and practice. The knowledge engineering review, 10(02), 115-152.

Yang, S., & Feng, N. (2008). A case study of industrial symbiosis: Nanning Sugar Co., Ltd. in China. *Resources, Conservation and Recycling*, *52*(5), 813-820.

Yang, C.C., and Sageman, M., (2009). “Analysis of terrorist social networks with fractal views.” Journal of Information Science, 35(3): 299□320.

Yeung, C. M. A., Liccardi, I., Lu, K., Seneviratne, O., & Berners-Lee, T. (2009, January). Decentralization: The future of online social networking. In *W3C Workshop on the Future of Social Networking Position Papers* (Vol. 2, pp. 2-7).

Yu, C., Davis, C., & Dijkema, G. P. (2014). Understanding the evolution of industrial symbiosis research. Journal of Industrial Ecology, 18(2), 280-293.

Zhang, L., Yuan, Z., Bi, J., Zhang, B., & Liu, B. (2010). Eco-industrial parks: national pilot practices in China. Journal of Cleaner Production, 18(5), 504-509.

Zhang, Y., Zheng, H., Chen, B., Su, M., & Liu, G. (2014). A review of industrial symbiosis research: Theory and methodology. Frontiers of Earth Science.

Zhu, Q., Lowe, E. A., & BARNES, D. (2007). Industrial symbiosis in China: a case study of the Guitang Group. *Journal of Industrial Ecology*, *11*(1), 31-42.

Zukin, S., and DiMaggio, P., (1990). Structures of capital: The social organization of the economy. Cambridge University Press, Cambridge, MA.

ANNEXE

Nous présentons dans cette annexe l'architecture fonctionnelle d'un prototype d'un réseau social vert (EcoBiose) ainsi que diverses informations portant sur le projet. Nous avons privilégié un scénario d'identification d'opportunité de synergie ayant un caractère auto-organisé. Le scénario retenu est le suivant:

- Une entreprise souhaite trouver un débouché pour une matière donnée.
- Une entreprise complémentaire est alors recherchée afin de créer une synergie avec la première entreprise susmentionnée.
- Afin de s'assurer de la faisabilité de cette synergie, une vérification préliminaire est effectuée auprès de l'entreprise complémentaire.
- Après cette vérification, les deux entreprises peuvent être mises en contact.

Le premier écran conçu est celui de l'identification de l'entreprise pour savoir si elle est productrice ou utilisatrice de résidus industriels. A été pris en considération le fait qu'une entreprise peut être à la fois productrice et utilisatrice de matières résiduelles.

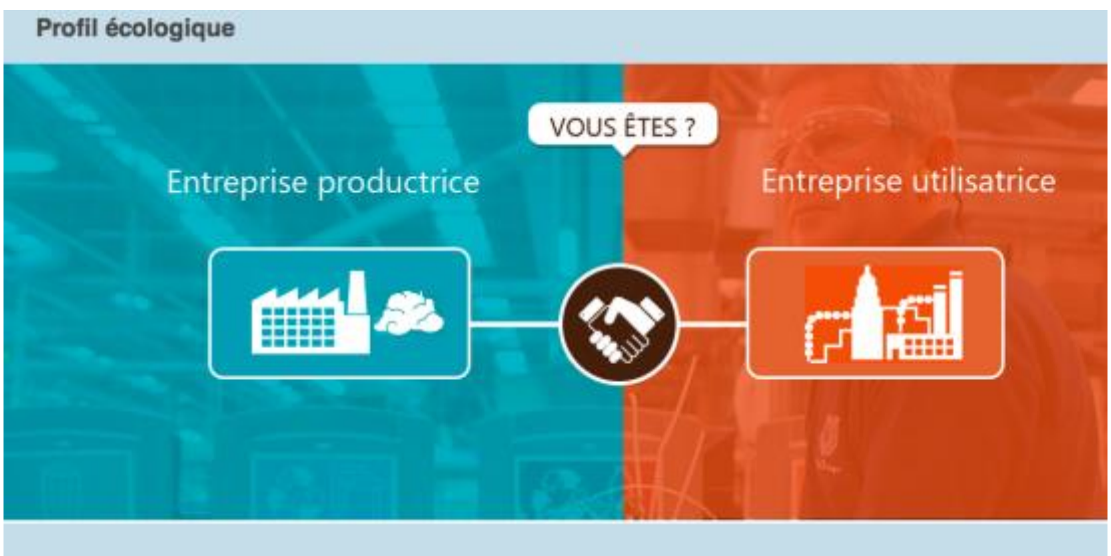


Figure A-1: page d'identification

Le deuxième écran représente une interface de collecte de données sous la forme d'un formulaire interactif et intelligent.

À travers ce formulaire, il est possible défaire défiler les catégories de matières les plus utilisées via un carrousel ou de sélectionner des catégories de matières prédéfinies dans une liste déroulante. Suite à son choix, le visiteur aura la possibilité de sélectionner plusieurs choix de sous-catégories de matières, de choisir l'unité, la quantité de la matière en question ainsi que la fréquence des collectes. Le table suivant présente la liste retenue:

Tableau A-1: liste de sous-catégories de matières

Catégorie de matière	Sous-catégorie de matière
Bois	Bois brut, retailles, copeaux, poussière et Sciure, palette, contreplaqué, bois traité, bois contaminé, autre
Charbon & composés	Charbon, anthracite, coke, Graphite, noir de carbone, autres
Eau	Eau potable, eau de pluie, vapeur d'eau, eau contaminée, eau traitée, boue de traitement des eaux.
Huile	Huile minérale, huile végétale, filtre à huile, huile de coupe, autre
Matériaux de construction	Asphalte, bardeau d'asphalte, béton, brique, ciment, gypse, stucco, matériaux d'isolation, pierres concassées, autres
Papier	Papier de bureau, journaux, papier mélangé, papier contaminé, autre
Carton	Carton, carton ciré, carton contaminé, autre
Peinture & résidu	Alkyle, époxy, latex, polyuréthane, boue de peinture, contenant à peinture, autre
Plastique & caoutchouc	Polyéthylène de téraphtalate, polyéthylène haute densité, polychlorure de vinyle, sac et pellicule, polypropylène, polystyrène, résine, plastiques mélangés, caoutchouc, contenant en plastique, pneus hors d'usage, autre
Résidus verts & agro-alimentaires	Résidus agricoles et forestiers, résidus agro-alimentaires solides, résidus agro-alimentaires liquides, autres.
Sol	Sable, gravier, argile, végétaux, sols contaminés aux métaux lourds, sols contaminés aux hydrocarbures, autres.
Tissu & textile & fibre	Textile propre, textile souillé, fibre naturelle végétale, fibre naturelle animale, fibre naturelle minérale, fibre synthétique, cuir propre, cuir souillé, autre.

Tableau A-1: liste de sous-catégories de matières (suite)

Verre	Contenant en verre, pyrex, verre concassé, fibre de verre, poussière de verre, autre.
Acide	Acide chlorhydrique, acide sulfurique, acide phosphorique, acide aminé, autre
Base	Carbonate, chaux, solution de soude caustique, autre
Métal & boue de métal	Acier doux, Acier galvanisé, Aluminium, Cuivre, Zinc, Nickel, Plomb, Alumine, Métal ferreux, Métal non ferreux, Métaux mélangés, Résidus de métallurgie, Boue procédé, Minerai, Laitier, Scorie, Contenant métallique, Métaux (toutes catégories)
Solvant & résidus	Acétone, Alcool, Solvant halogéné, Solvant chloré, Solvant non-Chloré, Bone, autre.
Composé organique	Polymère, Colle, Floculant, Hydrocarbure, Glycerine, Pigment organique, autre.
Composé inorganique	Sel minéral, Silice, Gypse, Brique réfractaire, Pigment inorganique, Gaz, Catalyseur et résidus, Carbone inorganique, autre.

Le formulaire offre l'option de saisie semi-automatique qui va permettre d'afficher instantanément, au fur et à mesure de la frappe d'un mot clé dans le champ dédié, des propositions de requêtes et les recherches les plus saisies en rapport avec un terme.

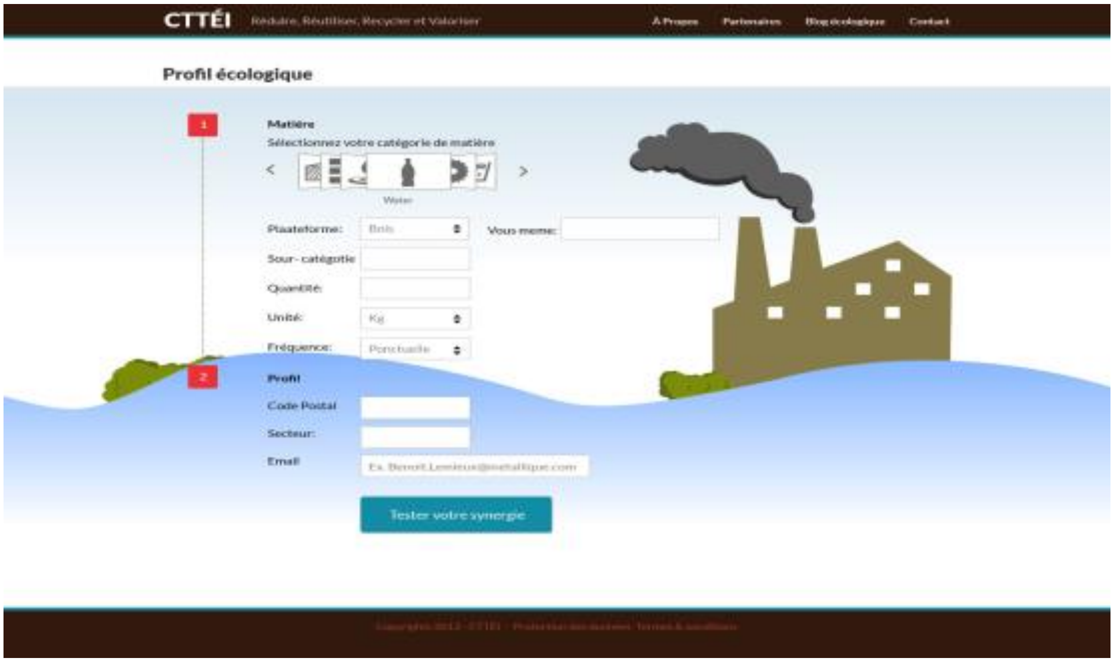


Figure A-2: identification matière et profil de l'entreprise

Le troisième écran va nous permettre de caractériser la matière, dans le sens où on va déterminer la présence ou l’absence des contaminants ainsi que le pourcentage de contamination. Le but ici est de définir pour chaque catégorie de matière une liste de contaminants les plus susceptibles d'être présents et probables, et ainsi d’affiner le choix et la description de la matière.

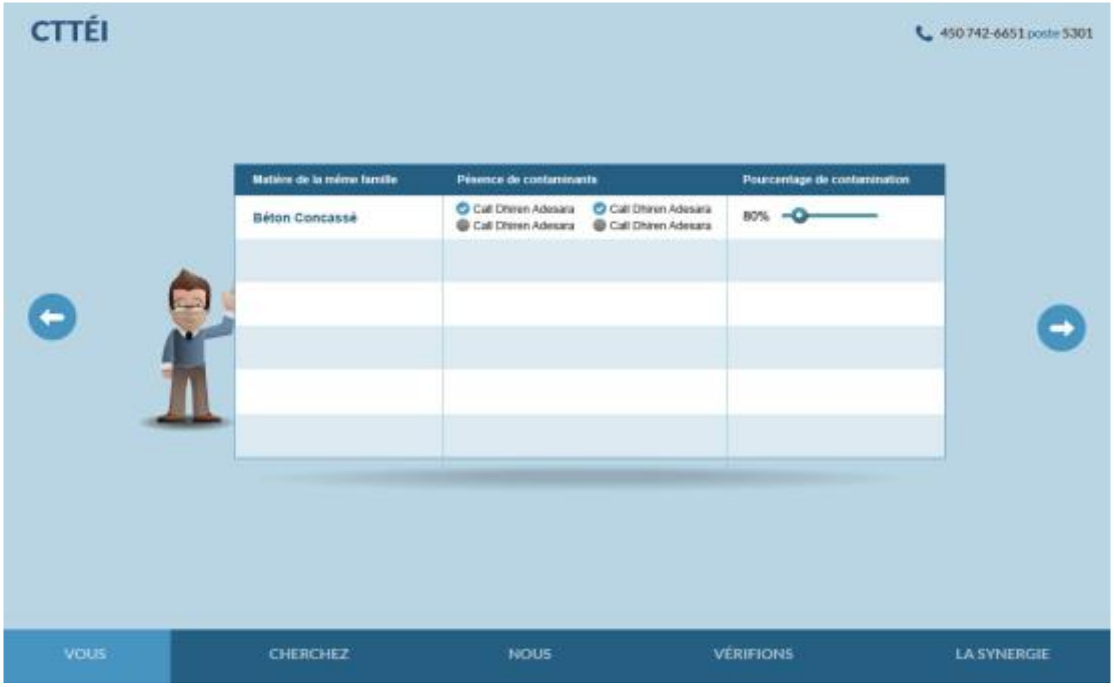


Figure A-3: la présence de contaminants

La page suivante présente la matière résiduelle retenue ayant fait l'objet d'une valorisation selon le CTTÉI et qui a (pourra) été (être) utilisée et réutilisée dans des usages différents. Dans ce table on a ajouté deux critères effort / bénéfice.

L'effort a été défini comme étant la charge allouée pour transformer et/ou analyser la matière. Par exemple, plus il y a de transformation à faire sur la matière, plus l'effort est élevé. Le bénéfice réfère aux avantages économiques. Plus il y a d'avantages économiques, plus le facteur-bénéfice est grand. Par exemple, le table suivant présente les différents usages possibles pour le béton concassé en fonction de la popularité et d'un arbitrage entre effort et bénéfice.

Figure A-4: identification des différents usages de la matière résiduelle

La page suivante est une page d'authentification. C'est une manière de charger le profil, récupérer les paramètres personnels et d'assurer la sécurité et la confidentialité des données des différents utilisateurs. Chaque utilisateur de la plate forme (administrateur, chargé de projet, animateur et entreprise) possède des privilèges d'accès définis auparavant par l'administrateur de l'application. Il doit saisir son identifiant et son mot de passe à travers le remplissage d'un formulaire afin d'accéder à son espace personnalisé.

Nous avons planifié deux façons pour s'enregistrer et se connecter ;

1. la façon classique avec informations de base sur l'entreprise et la personne représentant l'entreprise;
2. Une identification sociale en utilisant l'API JavaScript de LinkedIn ce qui va permettre aux visiteurs de s'authentifier à l'aide de leur compte LinkedIn. Cette authentification via Linkedin va nous permettre à la fois d'affirmer le caractère professionnel et formel de notre plateforme, et de présenter des recommandations en se basant sur le comportement de l'entreprise. C'est un moyen pertinent pour rationaliser l'expérience des entreprises avec la plate forme.

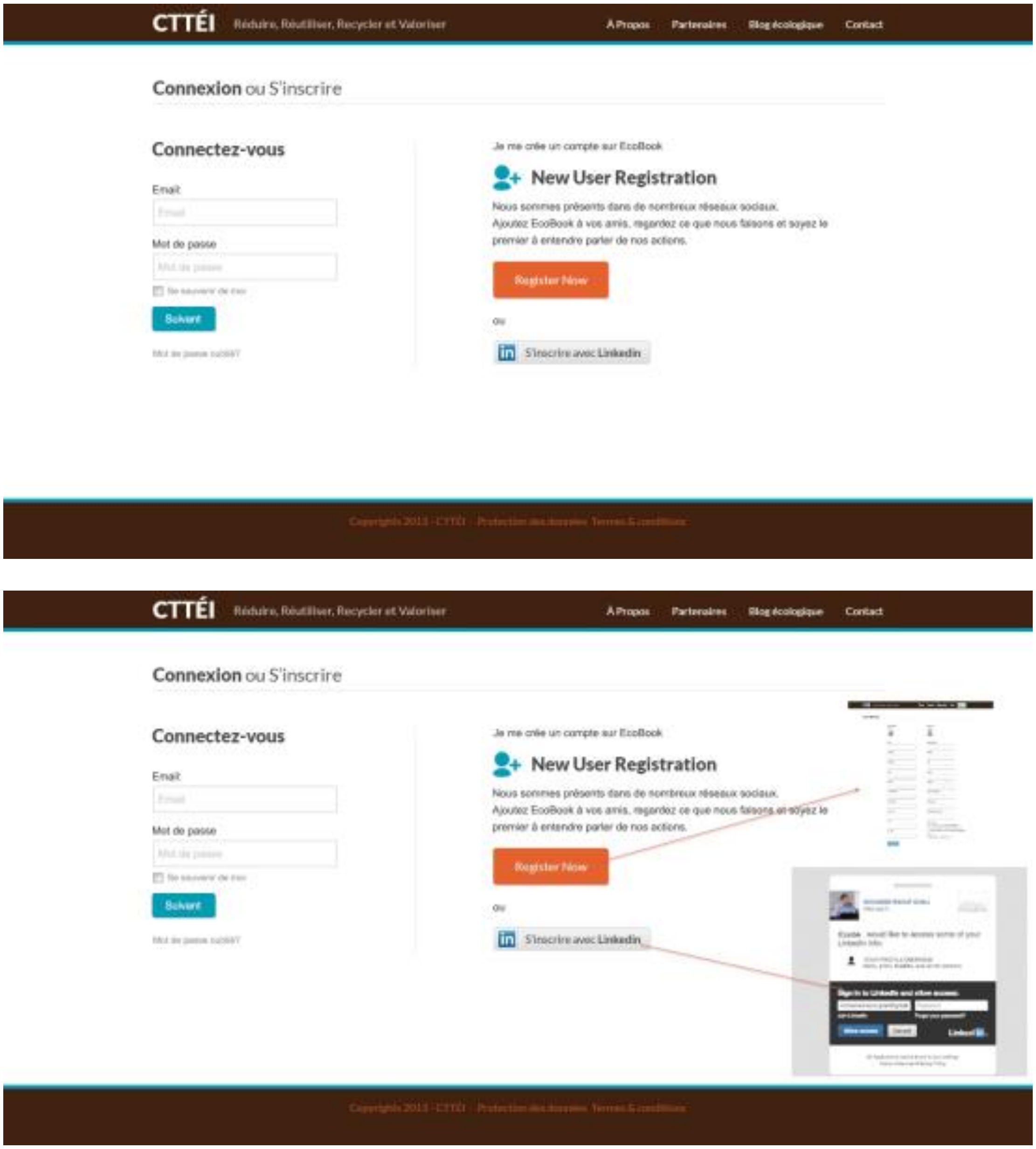


Figure A-5: authentification utilisateur / visiteur

L'écran suivant affiche les pistes de solutions à savoir : une proposition d'une entreprise complémentaire, ou une proposition d'une symbiose existante dans le territoire proche du demandeur (proximité géographique), ou encore une présentation d'un facilitateur ou une offre d'option de recyclage avec une liste de recycleurs. Pour cela, nous avons élargi les règles de maillages en mettant en place des rubriques de règle de maillage plus flexibles. Par exemple, une rubrique qui ajoute automatiquement des catégories de matière et des règles de maillage à partir des synergies proposées. On a également affiné le choix de la matière par un arbitrage entre l'intérêt de la matière et la faisabilité d'une synergie de cette matière.

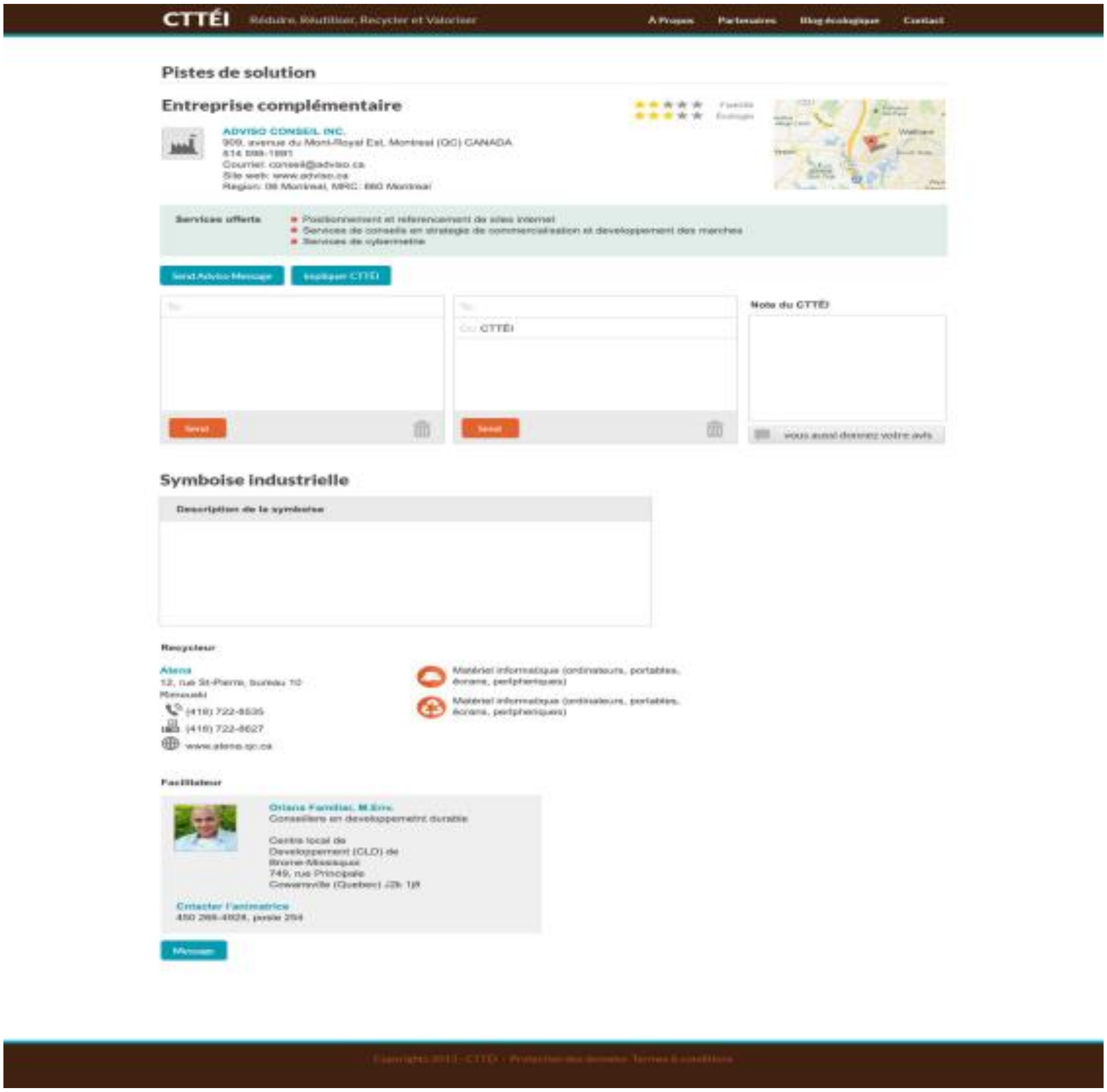


Figure A-6: description détaillée des pistes de solution

Enfin, l'écran suivant est celui d'un table de bord. L'objectif de celui-ci est de centraliser l'information de chacune des synergies par client, c'est-à-dire :

i. les matières susceptibles d'être échangées,

ii. les synergies proposées et leur évolution.

Voici quelques éléments qui pourront être intégrés dans cette interface :

- Entrée des informations sur les entreprises et leurs matières
- Autodétection des synergies
- Suivi de l'état d'avancement des synergies (KPI)
- Consignation des idées de synergies (des articles écologiques; Buzz écologique) et conservation des traces des suivis
- Information sur les matières et les entreprises
- To-do list afin de simplifier la démarche d'éco-responsabilité (des étapes bien structurées, clarification de la procédure administrative). Par exemple, la démarche nécessaire pour obtenir le certificat d'autorisation du ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques (MDDELCC). La liste à faire (To-do list) apporte également de l'information structurée sur le réseau des centres collégiaux de transfert technologique (CCTT), sur les programmes de financement liés à la recherche et d'autres informations sur le réseau professionnel développé par l'équipe du CTTÉI (MDDELCC, MFE, CPEQ, etc.).

Cette partie ne sera pas développée dans le cadre de ce projet

Figure A-7: tableau de bord